coopi: a custom fitted chair for the modern home workspace combining manual processes with robotic 3D printing

integrated product design thesis by lean van den dikkenberg

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coopi: summary

figure 1: the final 1:1 prototype

Summary

Chances are that you, the reader, have been working from home during this pandemic. Working from home has been more common than ever before and is predicted to stay. However, chairs have not adapted yet: office chairs are complicated and bulky products. They are designed to be adjustable to multiple users, but are not the best solution for working in a nicely styled living room. This design project aims to develop a stylish chair that fits the home working environment while offering a personal, comfortable fit.

This design process is driven by the opportunities and limitations of digital manufacturing. The benefits of 3D printing seem promising, but can be time consuming and costly. This project focuses on realistically applying the manufacturing techniques for this scenario and for the start-up client. During an extensive ideation process, it was explored how to manufacture the seat by printing, how to add comfort, how to make it sturdy, stylish, and most importantly: how to do this in a manner that can be adjusted to the dimensions of the user.

This resulted in Coopi, a chair design that combines the strengths of robotic 3D printing with the benefits of a manual upholstery process. This, to avoid long and expensive printing times. Coopi is designed to showcase a bold, open and trendy character that fits in modern home workspaces while visually communicating the combination of manufacturing processes.

Finally, a 1:1 prototype was built in order to validate the concept (figure 1).

Introduction

Welcome to the written part of this project. Writing was only a small part in the whole, but this report highlights the most important insights, design steps, conclusions and recommendations. Hopefully, it will spark your enthusiasm and interest in this concept. In this report, you can read about the journey towards Coopi: a custom fitted chair for the modern home workspace combining manual processes with robotic 3D printing. At the same time, this is the journey of graduating from Integrated Product Design, a master from the faculty of Industrial Design Engineering at Delft University of Technology. This graduation opportunity was provided by Zon&Hoofd, overseen by Erik Tempelman, Eliza Noordhoek, and executed by Lean van den Dikkenberg (figure 2).

Lean van den Dikkenberg
behance.net/leanvandendikkenberg

figure 2: hi, its me holding the seat of the Coopi

Assignment

"[Design] a tailor-made chair that you don't want to hide in your office, but deserves a place in the middle of your living room."

This sentence, written in the initial assignment brief (Appendix A), immediately stands out. It highlights and summarizes the vision of the client on this project. By using digital manufacturing techniques, the client wants to offer a chair that fits well to the body. All the while maintaining a clean, beautiful characteristic, as opposed to complicated ergonomic desk chairs.

The project was clearly scoped. Focus should lie on *"the design and the technical aspect of the realization of the chair."* With this, the project should be about designing a chair that can be manufactured realistically while offering comfort and while looking good. Building a 1:1 prototype was the preferred outcome for the project (see figure 3).

Since this scope is already broad enough for one graduating student, the client decided to keep this project focused on the above, while areas such as ergonomics, anthropometrics (measuring the body) and parametric modeling were planned to be investigated by another student. The full assignment brief is found in Appendix B.

figure 3: analog picture of the prototype

coopi: contents

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2. Con-text

coopi: 2. context

Conxtext

2.1 Client introduction

You might be familiar with the names of Marcel Breuer, Frank Gehry, Eero Saarinen, Zaha Hadid or Alvar Aalto. All of these share strong parallels to this project and to its client. As you may have guessed, they were or are all architects, and what's more, they have all designed chairs. Just like the client connected to this project does.

The client in question here is Zon&Hoofd, a start-up founded by Koen Hoofd and Leon Zondervan. These two Dutch architects dream of designing a revolutionary chair. Based in the Netherlands and Portugal, they have previously worked on various architectural projects in and around Rotterdam, and are now stepping into the world of furniture design. Marcel Breuer and the other architects already mentioned above are by no means the only examples of chair designing architects out there. One may even start to wonder – why are architects so obsessed with chairs?

Art Historian and writer Agata Toromanoff, who wrote the book Chairs by Architects, compares the phenomenon to a 'rite of passage' (Toromanoff, 2016). Toromanoff mentions: "Almost everyone I spoke to says that a chair is a way of demonstrating an architect's credentials as a designer to a wider audience." After all, most people share a more intimate connection with a chair than, say, with a building.

Another explanation could be that architects design chairs to complement their buildings. For instance: Van Der Rohe designed his Barcelona chair initially for the Barcelona Pavilion, Breuer's Wassily chair was designed for Wassily Kandinsky's apartment and Aalto's No. 41 Lounge Chair was designed specifically for a tuberculosis asylum (Alderson et al., 2013). The definitive answer may lie somewhere in the middle, or perhaps be found in another explanation altogether. However, to find the right answer one should probably write an anthropological thesis, and that is not the goal here.

First and foremost, a relevant point to mention here is the relevance of the client in particular to this design project. Zon&Hoofd is a start-up that has no previous expertise or experience in furniture design. Neither do they have any relevant facilities or connections at their disposal yet. Their experience with (digital) manufacturing techniques and ergonomics, as well as their budget may differ from larger furniture manufacturers. Still, the dream of revolutionizing office seating (combined with achieving commercial success) is what has motivated Zon&Hoofd to venture into the field of furniture design.

2.1.1 File to factory approach

Since the client has only just started out, it is yet not possible to identify current brand values or defining their current clientele. While reading the design brief, the term 'file to factory' stands out, and this makes perfect sense for a start-up company. During this project, it will become clear that the term is a little too optimistic, but it still clearly illustrates the approach the client wants to take. With quick innovation instead of years of research, a design driven innovation approach is well suited for a start-up company like this. There is no time or budget for years of research. At the same time, the company is small and young, untethered by company structures or regulation. The project is thus approached as a design opportunity, not as a way of solving problems that the clients' existing users encounter. These conditions have obviously had its implications on the outcome of this project, but more on that later.

2.2 Fieldlab UPPS

The Fieldlab UPPS is a TUDELFT affiliated research and expertise center focused on the development of Ultra Personalized Products and Services (or UPPS). Its goal is to accelerate innovation for clients, by the sharing of expertise in using 3D scanning techniques, smart sizing systems or parametric shape modeling (Fieldlab UPPS, n.d.). Zon&Hoofd plans to collaborate with the Fieldlab after this graduation project. UPPS will guide them in measuring the dimensions of the user, and in the translation of this data into a parametric model. Since this expertise will thus soon become available to Zon&Hoofd, the choice was made not to further research this topic during this project. Rather, we will be focusing on design for manufacturing and assembly.

2.3 3D Robotprinting

This project will be mentored by Eliza Noordhoek, who works at the Rotterdam based 3D printing company 3D Robotprinting (3DRP). The company is expert in printing large scale products with their self-developed robotic 3D printers. By working with Eliza, and indirectly with 3DRP, this design project has been able to gain additional insights from real practice. Notably, 3DRP is not a client to this project. While relevant information may be shared with them, the end result of this project does not have to meet this company's requirements.

coopi: 3. analysis

3. Analy-sis

figure 4: panton chair (1967)

3.1 Manufacturing - introduction

All of us are familiar with the Panton chair (figure 4), designed by Verner Panton in the 1960s. This chair is seemingly simple – crafted from just one material, without any upholstering, joints or mechanisms. However, it took Panton three years to find manufacturers willing to take on this engineering challenge: fifteen to twenty manufacturers tried and denied it. It took yet another four years to achieve the first serial production (Alderson et al., 2013). What's more, the original thermoplastic did not prove to be strong enough, and Vitra halted the production for eleven years (Vitra & Panton, n.d.) before bringing the same design back onto the market with injection molded polypropylene. This illustrates that the Panton chair was not as easy to produce as it may seem, but it also illustrates the importance of carefully considering the opportunities and limitations that come with a manufacturing technique.

Just like the Panton design, a chair is often built with (a combination of) manufacturing techniques like molding or machining. Digital manufacturing techniques (DM) such as 3D printing have been around for some time now, and have increased in popularity and availability: the desktop 3D printer used for the 1/5 scale models and prototypes (section 4.3) now only costs just a little more than €200,-. Any enthusiast can name multiple advantages for 3D printing: customization, localized production, design freedom and more. *So why are not all chairs printed already?*

3.2 Consideration on DM selection

The approach of digital manufacturing draws its strengths from being operated by a computer program. When a computer determines where material is added or removed (introducing the terms additive and subtractive manufacturing), every resulting product could be unique, something that can not be achieved with molds, for example.

The term additive manufacturing can be used interchangeably with 3D printing, but this is an umbrella term, there are many different possibilities. SLS, SLA and FDM are examples of different techniques. Each of those techniques will serve a certain purpose: the FDM process is the most cost effective, while SLA can print with greater surfacing details. If for instance a nylon or metal product is wished for, SLS/SLM may be the option of choice. For now, it may not be necessary to explain the workings of each principle in detail. Worthwhile to mention the most impacting factor for this project: cost.

3.3 Cost impact on technique selection

It is pretty easy to answer why not everything is printed nowadays: it is costly because it is slow. Yes, when designing an injection molded product, one should invest in machinery and molds, which can be expensive. Now, the big difference between molding and 3D printing is the scale and speed of production: an injection molding machine could produce a piece in just minutes; the investments and the machine rate (€/hour) are distributed over a large number of products. This also does not yet include fixed costs such as material & components, labor & assembly, packaging, or quality control (Tempelman, 2021). Simply said: the more products you can make, the cheaper it will become.

The Panton Chair mentioned earlier can be molded in three to four minutes (Victoria and Albert Museum, 2015), a speed that 3D printing could never compete with. Depending on the selected 3D print technique, the size of the object and in what quality it needs to be printed (the higher the quality, the longer it takes), printing a chair could take hours. Also the manufacturing cost of a product varies with the different techniques: FDM being the most cost effective: around three times cheaper than SLA and about four times cheaper than SLS (Cox, 2021). Therefore FDM was selected as digital manufacturing technique.

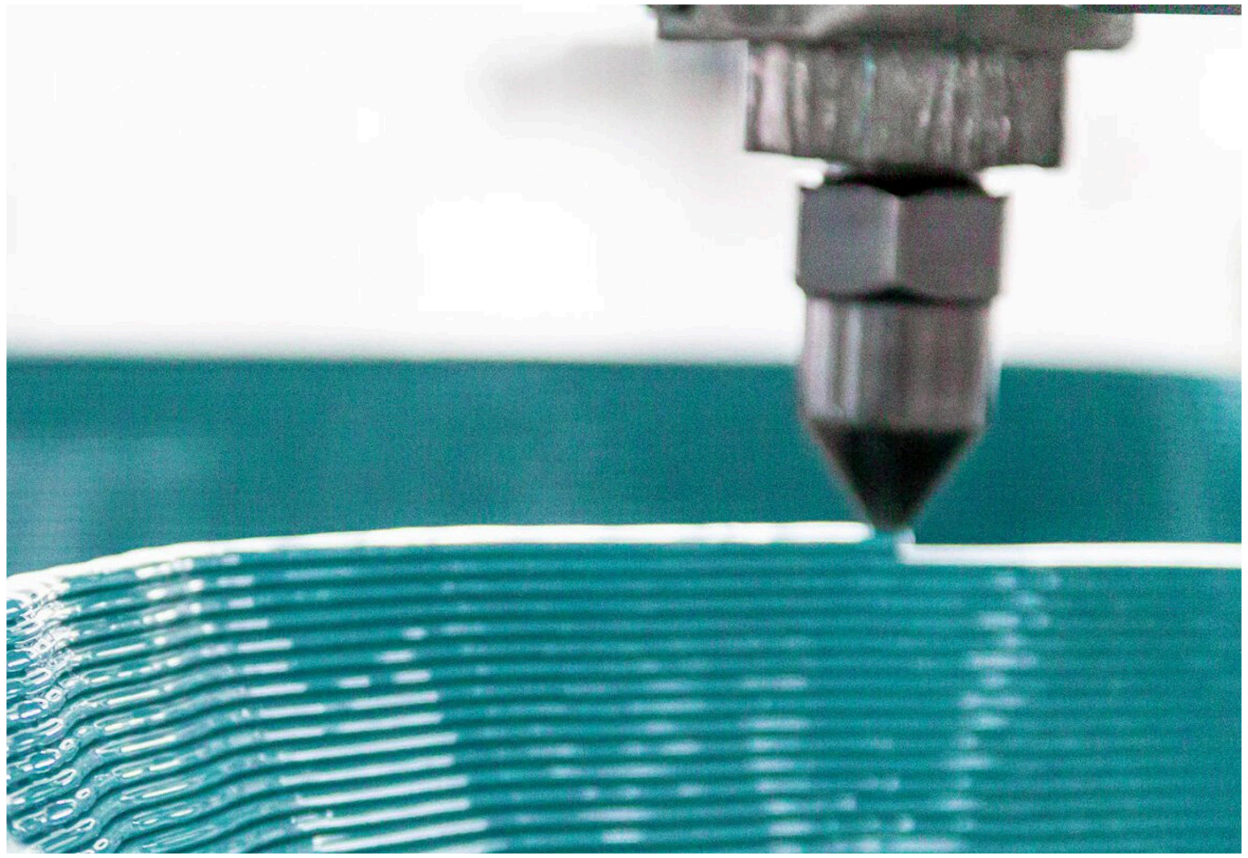

figure 5: print-head and stepwise appearance

3.2 FDM

The acronym FDM stands for Fused deposition modeling. This is a technique in which a molten thermoplastic is deposited from a computer controlled moving print-head (figure 5). The print-head deposits the thermoplastic freely on the XY plane, and then moves up the Z-axis to extrude a new layer on top of the previous layer. In the upcoming section we will highlight a few topics relevant to the process of FDM printing.

3.2.1 Resolution

All 3D printers work in three dimensions, obviously, but not all 3 dimensions maintain the same quality with an FDM printer. A FDM printer works in the XY plane, and on the Z-axis. The computer controlled print-head has great freedom in the XY plane and is capable of precise control when a single layer is being deposited. However, when the first layer -let's say 1mm layer height (figure 7), is deposited, the printer moves 1mm up along the Z-axis to discard another layer. This leads to precise control in the XY plane, but a stepwise appearance in the Z-axis (figure 5). There is some control over the thickness of this layer. The thinner the layer height, the smoother the appearance on the Z-Axis, but also the longer the print time. So a shorter print time and thus a lower resolution print is more economical.

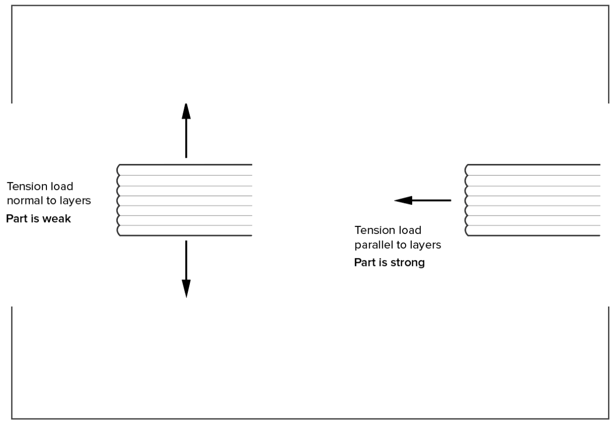

figure 6: the direction of the tension

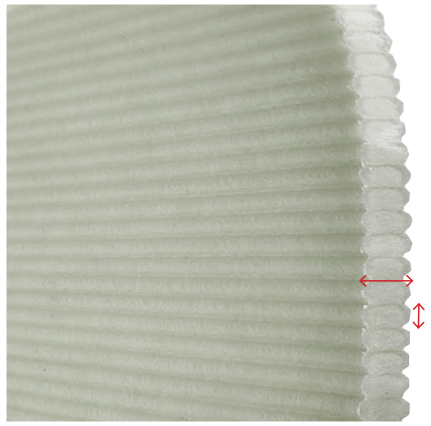

figure 7: layer-height (vertical) and wall thickness (horizontal)

3.2.2 Anisotropy

When it comes to FDM printing, it is important to note that unlike molded or machined materials, a FDM printed material is not equally strong in all directions. A thermoplastic can only be extruded from the print-head at a certain (material dependent) temperature. When cooling down, the deposited line hardens and forms entangled polymer chains. However, when a new layer is deposited onto an old layer, the adhesion is limited. This leads to parts being strongest in the direction of the deposited line. This means that a FDM printed part is anisotropic and if the part experiences a directional load, this property should be kept in mind. In practice the mechanical properties of a printed material are hard to determine and depend on factors such as print temperature, print layer time, airflow (cooling), humidity during printing, etc. However, a study performed at 3DRP suggests mechanical properties (break strength) to degrade by [confident]compared to injection molding the same material. This is in the most favorable print orientation: parallel to the layer. In the least favorable orientation, normal to the printed layer (figure 6), the break strength is degraded by another [confident], compared to the optimum print orientation (Mabtoul et al., 2018).

3.2.3 Minimal layer time/return time

As mentioned earlier, the shorter the print time, the more costs can be reduced. But there is a physical limitation to the minimum duration of which the printer can deposit one layer before starting a new layer. When a new layer is deposited onto a previous layer too soon, the entirety is too warm and not hardened enough -and may collapse. Therefore the printer has a minimal layer time set. In some cases a printer is programmed to slow down its moving print-head to ensure the minimal layer time passes, in other cases the printer lifts the head and waits before starting a new layer. On the other hand, if it takes the printer too long to start a new layer, the previous layer has cooled too much which degrades the strength of the part (Noordhoek, 2021). In practice the minimal layer time is dependent on the material, print environment, layer height and wall thickness. Typically at 3DRP a minimal layer time of [confident] seconds is used for glass-fiber reinforced polypropylene with 1,2 mm layer height (Noordhoek, 2021).

3.2.4 Design freedom, support and overhang

When it comes to FDM printing, some might say: the sky's the limit. But actually, gravity is something of an issue as well. If a design is not properly prepared for 3D printing, it may fall over or start drooling. When printing, a part has to support itself and is limited to overhangs of typically 45° maximum (3D Robotprinting, n.d.), as illustrated in figure 8. Anything that slopes more horizontally than 45° needs support material, which should ideally be avoided as it has to be manually removed and leaves undesirable marks on a printed part. The designer is thus challenged to creatively work around these set limitations. For example by changing print orientation or by avoiding rounded corners.

3.2.5 Post processing

Depending on the function of the design, it is not always necessary to further process a part after printing. Sometimes however, it may. A 3D printed material, like the glass-fiber filled PP at 3DRP is processable similarly to wood. It can be sawed, machined, drilled, sanded or polished.

figure 8: guidelines for overhang

3.3 Benchmark

At the early design stages, a market scan can shape the concept by deviating from the competition. The brief for this assignment sounds novel and possibly lucrative. But what is out there already? Why should the intended audience opt for this chair design in particular? Or what stops the users from buying a printer instead of a chair?

3.3.1 Patents

First of all, a competitor and a patent scan was performed, see Appendix C: no possible infringe-able patents, or comparable concepts were found. Apart from that, concepts are only patentable when they can be described as *novel* and *inventive*. A CAD file, shape or mesh printed with non-novel technology is therefore hard to patent. The Patent office at TUDELFT sees few opportunities for commercial patent success (Goren, 2021).

3.3.2 Targeting & value mapping

In order to avoid this concept to be easily copied by competitors (or easily printed by individuals at home, hurting the commercial success), it should deliver distinctive value that cannot simply be downloaded.

By comparing a data set of desk- and dining chairs (Appendix D), it becomes evident that there is a clear gap between the values of 'ergonomic' chairs and 'home' chairs (figure 9). Chairs that are perceived as ergonomic are not perceived as suited for home and vice versa. Therefore it makes sense to target a chair suited for this particular market gap. The value proposition of a customized 3D printed chair clearly distinguishes itself from both office chairs and from dining chairs. The concept should separate itself from both. Price-wise the concept should therefore also be separated from the high end desk chairs and from dining chairs. A non-adjustable and immobile 3D printed chair could not offer the same benefits as a high end office chair (more on this in the next chapter) and should therefore be cheaper. At the same time a customized concept can deliver added value over regular dining chairs and should therefore be priced more as valuable. The according price gap would be between €500,- and €750,-

figure 9: value mapping exersises show opportunity for targeting the concept

3.4 Expert interviews and research on sitting

figure 10: F. Tilman during interviewing (2021)

As described (page 6 & page 13), this project is mainly concerned with how the chair is designed and built, not necessarily with ergonomics, measuring comfort or collecting anthropometric data. That could be an entire thesis on its own (as it was also intended to be). However it would be senseless to design a chair without any knowledge of what 'sitting correctly' is, or if it even exists. In the following sections (3.4.1 to 3.4.8), the concepts of seating according to experts and literature are discussed. This includes quotes from expert interviews with F. Tilman, founder of De Zitacademy (figure 10), J. Koppenaal, owner of ergonomic chair store Bureastoelwijzer, an email exchange interview with occupational therapist M. Brüll, as well as literature research. The entire expert interviews can be found in Appendix E.

3.4.1 Trunk-thigh angle

Sit up straight! A phrase that pretty much every parent will have said to their children at some point. Probably, most people tell it to themselves once in a while, as they are slouching behind their computers. But is sitting up straight truly beneficial? Experts have a different interpretation. "We are stuck with the notion that we have to sit straight up with angles of 90 degrees." This notion, according to Tilman, is complete nonsense. Koppenaal agrees: "90 degrees is outdated. A larger angle between trunk and thigh (figure 11) ensures a tilted pelvis and relieves pressure on the lower back vertebrae." Also, a larger angle increases blood flow (Koppenaal, 2021), but a tilted pelvis is most important.

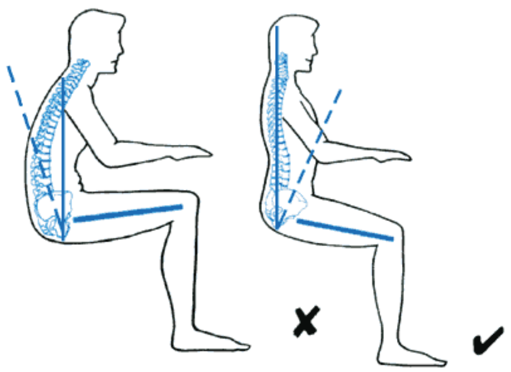

figure 11: an open trunk-thigh angle tilts the pelvis forwards and reduces tension on the inter-vertebral discs.

The statement that an open trunk-thigh angle is beneficial for relief of inter-vertebral disc pressure has been backed up by plenty of research (Harrison et al., 1999), however the exact angle is still debated.

Jamison et al., (2000) concluded an angle of 110 - 130° to be most natural, Keegan (1953) settled on a 135° degrees angle and NASA found that astronauts adopt a natural spinal curve in space at a 128° angle (Han Kim et al., 2019).

For sitting, however, the angle should be smaller. All of these sources above have focused on the most neutral spine curvature possible. For sitting, Groenesteijn et al. (2009) argued that a 120 degrees trunk-thigh angle results in greater neck flexion, which is not comfortable. A trunk-thigh angle of 105 would be advised for sitting and retaining a more natural neck posture. Harrison et al. (1999) also concluded that the angle for video monitor work should not exceed a 110°.

3.4.2 Benefiting a natural spine posture

Apart from a larger angle between trunk and thigh, and thus between seat pan and backrest, a chair can benefit one's posture through including a lumbar support. When the backrest of a chair follows the natural shape of the spine, it supports the natural s-shape. When a chair supports the back in the lumbar (or lower back) area, it relieves the pressure on the inter-vertebral discs and increases comfort (Harrison et al., 1999).

Research also shows that a tilted seat pan improves posture. The seat pan should be 'posteriorly inclined' by 5 degrees (the front of the seat tilted upwards). This allows for a better posture in combination with a lumbar support. The inclination makes the user fall back into the lumbar support of the backrest (Harrison et al., 1999).

3.4.3 Comfort

According to Vink (2004), the exact cause of comfort is unknown and the experience is completely subjective. The absence of discomfort does not automatically result in comfort, but the presence of discomfort does decrease the experience of comfort. Unfortunately there is no theoretical model readily available.

When it comes to chairs specifically, comfort and discomfort are related to the pressure distribution in the seat pan and backrest. With this, Koppenaal (2021) agrees; "experiencing comfort is related to feeling supported. [...] especially feeling uniformly supported." While seat cushioning provides comfort and aids the weight distribution, too soft of a material also causes the pelvic bone to rotate backwards and therefore resulting in the C-shaped spine. Think of a thick and comfortable couch or lounge chair: they make it nearly impossible not to slouch (Doucleff, 2018)

coopi: 3. analysis

3.4.4 Adjustability
"The Herman Miller Aeron is highly adjustable and can be adjusted in 750 thousand different positions" according to Eric van Dam, director of operations (BrandmadeTV, 2015). This may be a bold and somewhat vague statement, but to the Herman Miller company, this is clearly seen as a selling point. The more adjustable the chair, the better it may fit your body. This may be true, but there is also a downside: "A chair may have five different ways of adjusting, that leads to loads of different setups and will only confuse people." (Tilman, 2021). Even worse, surveys among desk chair users show 63% never bothers to adjust their office chair at all (Groenesteijn et al.,2009).

"Once a chair has been adjusted to the user, it should be left alone, Koppenaal (2021) explains, adjustability is only for making the chair fit to the body. For example, when the seat pan is too long, either the user's knees are pressed against the front of the seat, or the user will not be able to be fully supported in the backrest lumbar area. Therefore, a chair needs to fit well, but once adjusted there is no need for change.

3.4.5 Movement
From the expert interviews, it becomes clear that moving while sitting is beneficial for the user. "Peter Opzwik [designer of the HAG Capisco] said, the best working position is the next one" Koppenaal (2021) quotes. But especially Tilman is devoted to the notion of movement. A chair with a good tilting mechanism helps to support the user in different positions. Tilman (2021) explains it as 'shear force': when a chair does not move, the user will lean against the backrest and will push themselves out of a correct posture. When a chair utilizes an excellent tilting mechanism, the correct posture is maintained while moving.

Tilman is a big advocate of sitting on balance stools, where the user can tilt their own pelvic, without being able to slouch against the backrest. On the other hand, Koppenaal does not think of these stools as the best solution: "The biggest misconception is that a stool is a good solution to work on the entire day, [...] the most important movement is standing up and working three times a day for 30 minutes while standing."

3.4.6 Regulations
The Dutch government has also been meddling in the conversation of what good seating is. The health and safety law (known in Dutch as Arbowet) is a fairly vague law which requires the employer to arrange a healthy working situation. The Arbowet prescribes the following: "The work chair is stable, has a height-adjustable seat and a backrest, the height and angle of which are adjustable and gives the user freedom of movement and a comfortable working posture." (Overheid.nl, 2020)

To help employers select suitable chairs that are in accordance with the Arbowet, the NEN 1335 and NPR 1813 guidelines exist. They describe the amount of dimensional adjustability a chair should have. However, these guidelines do not have a legal base. "The employer is required to offer suitable chairs, however, the law does not force employees to sit in them" (Brull, 2021). Balance stools are a good example of this: they do not meet the regulations, but employees can still choose them.

The reputable company of Herman Miller also has many non NPR1813 chairs. According to Koppenaal (2021): "employers often ask for a NPR 1813 chair, thinking these are good chairs. That's not true at all. [...] I know many non NPR chairs that are much better."

To sum up the government guidelines do not necessarily provide the best seats according to the experts, it is perhaps not surprising that employees sometimes opt for chairs that do not follow the guidelines.

3.4.7 Trends
Dutch Ministry of Infrastructure and Water Management concluded from their research that working from home will stay a relevant theme in years to come. (Ministerie van Infrastructuur en Waterstaat, 2021) According to them, employers are willing to facilitate this by making investments in for instance online meeting tools or good chairs for their employees at home.

Tilman (2021) and Koppenaal (2021) have also observed these trends, but from their experience, the end user's awareness is growing due to corona: "Working from home creates extra awareness. All of a sudden people are responsible for how they sit", Tilman says. Koppenaal agrees and mentions: "People are looking for a good solution that does not bring the office in their homes. [...] Often people are looking for pleasing design, these are people from middle and high income."

3.4.8 Conclusion
To sum up the gained insights: can a static non adjustable chair be an ergonomic solution? "It is a complex story [...] you cannot just design a chair that is the ideal solution for everyone, the best you can do is make a chair that can be well adjusted to lots of people." (Koppenaal, 2021)

Now, we know from previous research that the design of a chair can contribute to a correct posture and to comfort. Fitting the chair to the user in a way that uniformly distributes pressure and keeps the pelvic bone rotated forward will decrease discomfort and inter-vertebral disc pressure. A tilting mechanism will help to maintain the posture (Tilman, 2021).

Although Koppenaal is right to point out that adjustability ensures a chair is fit for the use of many different people. Though, adjustability is also often not understood nor used correctly. This renders it an advantageous opportunity to design a chair that is optimized to one user and cannot be wrongly adjusted. Downsides however are that a 3D printed chair would not meet the regulations and the chair would only fit one individual. Therefore the concept might be a good product for the home working environment.

3.7 Personas

The Monobloc and the Panton chair are both polypropylene, injection molded, stackable chairs. In functionality, they are not the same chair, but they are not that different either. In value proposition however they vary enormously. Not only the monetary value is a play here (Vitra's Panton chair costs 40—50 times as much), but also the emotional value perception and the type of use. The Monobloc has been designed for users looking for a cheap, easy, lightweight (outdoor) chair, the In contrast, the Panton chair is loved by design and furniture enthusiasts over the world and is not only a chair, but also a statement. This means that the targeted use and user can have a huge impact on the value offering. Synthesizing personas help defining the targeted user.

The concept of a customized 3D printed chair with no movement or adjustability is not optimal for anyone or for every scenario. In the previous section (3.6), it became obvious that a non adjustable chair won't be working well in the office scenario. A non adjustable chair cannot be used by different users and will not meet the Arbowet-regulations, which makes them less beneficial for employers. As working from home will only increase in the future the concept should be targeted for the home working scenario. Within the home working scenario it is sensible to target a young and urban user-group as they are most likely to lack space for large office chairs. The personas (figure 12) also consist of higher educated consumers from mid and high incomes, as they are likely to work from home more frequently and are willing to pay more for a well designed chair (Koppenaal 2021).

Daniel

“my house is a collection of unique pieces of furniture that appeal to me, they reflect who I am. This chair fits that perfectly.”

age: 29
from: amsterdam
status: relationship
values: individualist, laid back, independent, personal development
hobbies: surfing, photography, visiting galleries
work field: creative

Maartje

age: 37
from: den haag
status: registered partnership
values: solidarity, honesty, critical world view
hobbies: gardening, attending seminars,
work field: linguistics

“The chair I’m looking for doesn’t have all kinds of unnecessary features that I don’t need. It fits my style, and is durable!”

Marc

age: 29
from: haarlem
status: single
values: hard work, success, social status
hobbies: F1, going out for drinks, crypto-trading
work field: financial

“for me, a chair should match my lifestyle. I am quite driven and I want to radiate that, so I deserve a quality chair. I’m also interested in Herman Millers, but my friends will be impressed by my customized chair!”

figure 12: personas Daniel, Maartje and Marc

3.8 Foam

From section 3.4.3 can be concluded that a chair needs soft cushioning in order to distribute pressure and increase comfort (or decrease discomfort).

There are various ways of achieving a soft surface on a chair. Think of molded foams or desk chairs with meshes. However, as each chair has to be customized, molding foam is not an option as this is not customizable. Also, upholstering a chair with mesh fabric is too ambitious (the client has zero facilities or experience in this field). Adding foam by hand has shown to be the most attainable option.

Through 1/5 scale models, the flexibility of polyether foams was tested for their ability to form double curvatures, see figure 15 and 16. It was concluded that foams up to 8 mm (equals 40 mm in real life) have the best properties of forming to

figure 13: modeling a human shape seat

figure 14: testing foams on 1/5 scale models of user body

the shape of a body, however the thinner variant of 6 mm (30mm 1:1) showed the most promising results. The samples can be seen in Appendix F.

A quick study like this provides some guidelines of what is possible and what is not. However it does not give the opportunity to sit in- and experience the comfort. Therefore four appropriate foams of various hard- and thicknesses were tested on real scale in a vacuum-chair, (figure 15). The thinnest foam of 20 mm PU HR 45 foam turned out to be most formable while being comfortable. The 30 mm Polyether SG40 foam turns out to be most comfortable, while still being formable, figure 16. The exact differences in comfort were hard to distinguish. Even though this test was not performed with a large number of participants, or for a long duration, it does give a good impression of the material that can be designed with. The results are described in Appendix F.

figure 15: a bag with polystyrene pellets that is vacuumed when a person sits in it, forming a hard surface exactly fitted to the shape of their body).

figure 16: 20 mm foam (left) and 30 mm foam (right) but adapt well to the shape of the body

3.9 Conclusions

Only a couple of pages in and already insights related to the feasibility of this concept have been unraveled. Before moving on to the ideation phase, first insights are summed up below.

Optimizing DM:
Digital manufacturing has various advantages, but most importantly, the concept should keep the printing time and therefore manufacturing cost low. FDM is the most suited, cost effective technique for this context. During the ideation process it will also be of importance to print efficiently, reducing the print time as much as possible and deal other found limitations of the FDM process.

Customized fit:
Delivering a good fit will be beneficial to the user as it will help posture and comfort. At the same time it delivers added value as it is a concept that is unique and can be designed without adjustment mechanisms.

Comfort:
Uniform pressure distribution will improve comfort. As upholstery will aid the pressure distribution, the concept should be upholstered as efficiently as possible. The most attainable upholstery method should be looked for.

Scenario:
An eye catching, effective design will set apart this concept from office chairs. The concept should be aimed at the home working scenario. A younger, urban and higher educated user group will benefit the most from this concept. They will have smaller living spaces in which they will be working from home. The estimated selling price should be between €500,- and €750,-

Deliver value to Zon&Hoofd:
During ideation, the capabilities of Zon&Hoofd will be taken into account. Exploring possible ideas such as tilting mechanisms, circular concepts or mesh upholstery could add value, however the capabilities of the client call for priority of short time-to-market and keeping the investment cost low.

coopi: 4. ideation

4. Ide-ation

coopi: 4. ideation

Ideation

For the development of this product, the ideation took place on multiple fronts. The product needs three ingredients: a customized digital manufactured seat, a component which provides comfort and a stable pair of chair legs. (And finally a 'meta' ingredient; styling, obviously.) These components (figure 17) were vastly dependent on each other. The chapters 4.1, 4.2 and 4.3 dissect the ideation and development of the final design into the themes of printing, upholstery and legs.

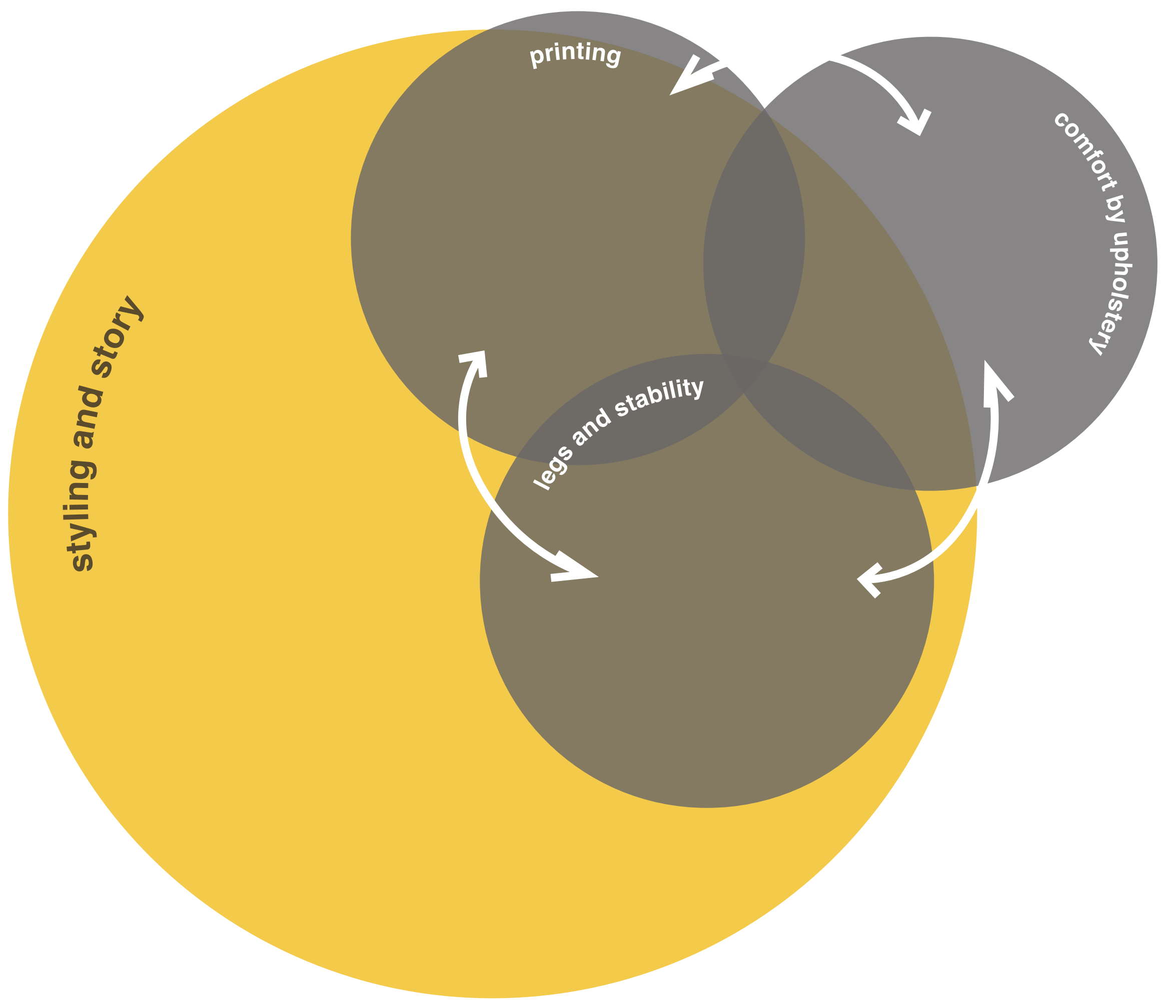

figure 17: the themes were interwoven during the ideation process

4.1 Upholstery

To make this concept successful, a practical way of upholstering is needed. A way that makes a 3D printed chair feel more comfortable. At the same time, upholstery should also make the concept be perceived as being more comfortable. The upholstering process should be realistic and as inexpensive as possible. This section describes the development through ideation sketches, scale models and expert interviews.

4.1.1 Main issue

The main issue to be dealt with was obviously custom fitting the foam and fabric. Nowadays, many desk chairs use pre-molded foams, since only one exact size is needed. The same applies to the fabric: the fabrics are exactly cut and can be glued to the foam. These processes are extremely quick which is an obvious advantage. The other big advantage of this process is that the pre-shaped foams require no glue to stick to the plastic seat, this offers a better opportunity of disassembly and reuse of parts, or reupholstery.

At first, ideas regarding comparable assembly processes were generated. As seen in figure 18 and Appendix G, ideas were generated that would speed up the process of assembly and finishing. In these initial ideas, fabric and foam were glued onto each other and pressed into a larger injection molded cover in order to avoid sewing and fitting. The advantages thereof are that manual labor would be reduced and that the injection molded cover could be reused, making a step towards circularity. However this also means that the initial investment costs for the client would be considerably higher as injection molding machinery and molds are needed. This concluded that adding an injection molded cover part would not be a suitable idea for the client and that extra manual labor for upholstering the chair would be favorable.

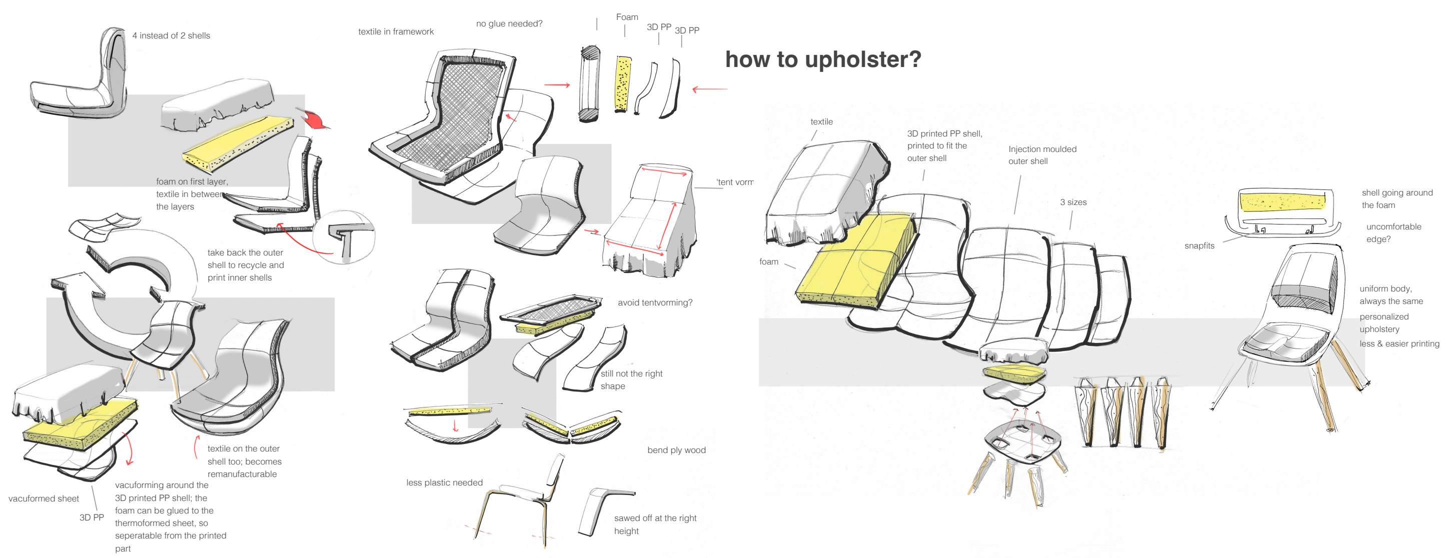

figure 18: initial ideas that explored accelerating the upholstery process, or improving circularity

figure 19: brining scale models (left) to upholstery shops

4.1.2 Manually upholstering

Through visits to upholsterer Studio Nest and the Hay store in Rotterdam (figure 19 & 22), more experience with the upholstery process was gained. Upholstering a chair can be a time consuming process. First of all, traditionally upholstering an individual chair can take up to four hours. Especially measuring and fitting of the fabric takes up 75% of the time, gluing, sewing and cutting is only 25% of the activity (van Besten, 2021). This is when the front and backside of the chair are upholstered, as those parts need to fit perfectly to each other. Apart from upholstering the front and backside, there are ways of only upholstering the front side, leaving the back unfinished. This obviously has its aesthetic advantages, more on that later, but it also saves half of the upholstery time. Therefore only upholstering the front side of the chair revealed to be the best option.

4.1.3 Sewable edge trim

An possible option for upholstering only the front of a chair is used on the Vitra Eames DAW armchair (see figure 20), for example. In this instance the fabric is sewed onto a so-called J-Clip: a PVC J-shaped profile that houses a metal profile. As the fabric is sewed onto the trim, the trim itself can be fastened to the edge of the seat. The internal hooks keep the trim into place without additional adhesive or fasteners.

4.1.4 Blind seam profile

A blind seam profile is a solution that has been utilized by Hay, for example figures 21 and 22. This solution looks more refined as it is smaller, does not visibly show a new PVC part, as opposed to the sewable edge trim. It also does not need to be placed over the edge of the 3D printed seat, leaving a smaller, lighter

figure 20: example of sewable edge trim: Vitra DAW

figure 21: blind seam profile used by Hay AAC 22

figure 22: blind seam profile illustrated in practice

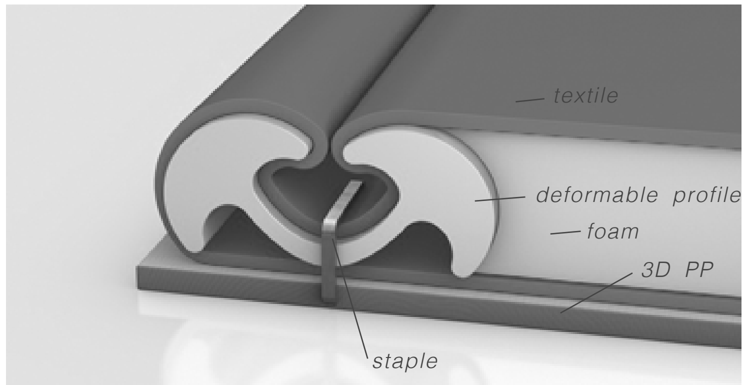

figure 23: the working of the blind seam profile illustrated

appearance. Hay store Rotterdam kindly gifted a defective chair and demonstrated the principle of the blind seam profile (Zaan, 2021). figure 23 shows the working: when the fabric is wrapped around the profile, it is stapled onto the plastic seat. Through the stapling, the profile deforms and covers the staple.

4.1.5 Stapling

In order to validate whether or not the blind seam profile is a possible solution, the 3D printed material had to be tested with staples. Samples of glass-fiber filled PP were tested. Initially a hand- and an electronic tacker were used, but the material was too hard (figure 24). With a pneumatic tacker, however, the material was tack-able, (figure 25). It must be said, obviously, that the staples need to be short and thin enough in order not to show any damage through the opposite side of the material. Therefore at the same time, the printed material is required to be thick enough.

4.1.6 Conclusion

The ideation development for the upholstering took many twists and turns. From investigating different options, themes such as minimizing manual labor or avoiding the use of glue, the concept settled on the use of a blind seam profile, a subtle way of upholstering only the front side of the chair. Leaving room for exposing the layers of the 3D printed material on the back side.

figure 24: staples not failing with electronic tackers

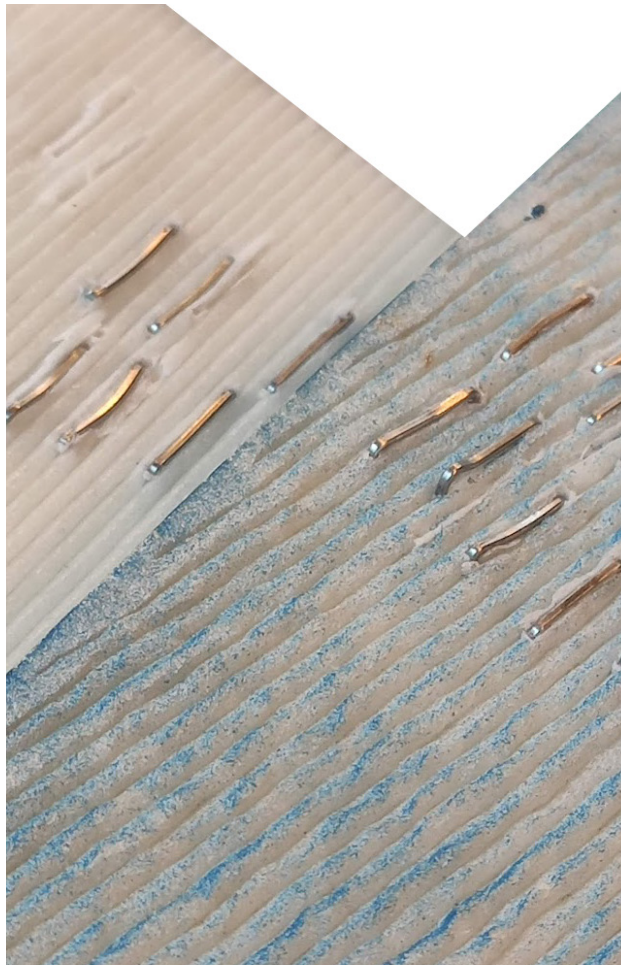

figure 25: successful stapling with pneumatic tacker

4.2 Print strategy

From the analysis phase, the first printing conditions became evident. Some conditions are strictly necessary to aid the printing process itself: think of designing a chair without 45 degrees overhang. While other conditions serve to aid the speed of production, such as designing a chair with a low resolution robotic 3D printer, to keep the printing time and cost lower. In this chapter we will look into how these conditions affect the design of the chair.

4.2.1 Print orientation
The nature of 3D printing allows the designer to strategically orient the model on the print bed. Figure 27 shows the impacts of rotating the print direction: the model on the left and the right clearly require more support material which results in a lower quality print and more finishing labor. Optimizing the print orientation will result in higher print quality as well as reducing print time and cost. To avoid additional support material (and thus printing time), a bucket shaped seat is best printed perpendicular to the symmetric plane. As demonstrated in figure 28.

4.2.2 Breakability
As mentioned in section 3.2.2, printed objects are more vulnerable based on their print orientation. In Appendix G, the effects are tested on scale models. Also printing perpendicular to the symmetric plane seems the safest option.

4.2.3 Printing in loops
Another advantage of printing perpendicular to the symmetric axis is the possibility to print in loops. Large pellet based 3D printers such as those at 3DRP operate best by continuously printing in loops. Small desktop filament printers can easily retract the solid filament, they can easily stop a printline and start somewhere else on the printbed. In contrast, larger printers cannot retract filament, but have to close off the nozzle, this results is a less precise result. Therefore, the printer can print best in continuous looping paths, visualized in figure 26. One loop can contain multiple seats which can be separated afterwards with a belt saw.

Printing multiple chairs at the same time, within one loop, is also more time- and cost-effective than printing one chair at a time. Every layer needs a minimum time to cool down before adding the next layer (see section 3.2.3). If every layer needs 76 seconds before it can start a new layer, it would be more effective to spend those 76 seconds printing one layer of multiple chairs, rather than printing one layer of one chair within the same amount of time.

For the reasons above, the concept of the chair settled upon printing multiple seats in one loop perpendicular to the symmetric plane.

figure 26: visualization of looped print paths

figure 27: printing scale models in differing orientations

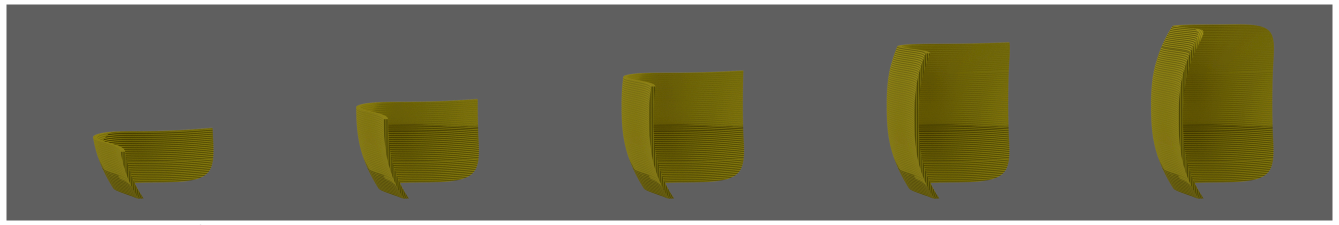

figure 28: printing perpendicular to the symmetric plane

4.3 Legs, attachment and stability

The last section (4.2) just described the print strategy and the reasons for choosing this approach. However, this strategy was also impacted by the concept development for the legs. This section explains how the concept developed as ways of combining a personally printed seat with a pair of chair legs were searched for.

Since printing can be done more effectively by printing multiple seats in a loop, it makes a lot of sense to combine a seat with a pair of prefabricated chair legs, for example made from metal or wood. Since the main purpose of legs is to raise the seat above the ground, these materials can easily be sawed off at one's popliteal height (from the floor, to the back of the knee) without adding costly printing time.

3.3.1 Initial exploration

The process started really taking shape by experimenting quickly with various shapes, materials and constructions. The goal of these activities was to quickly develop a sense of possible connections between seat and legs. Through rapid prototyping media such as clay, 3D print, iron wire, wood, and cardboard, several idea 'sketches' were tested, as can be seen in figure 29.

Quickly enough these models gave insight on the need for proper connection between seat and leg. Any separate leg that has been attached to a seat has great tendencies to bend, break or shear. Upon closer inspection of the models, any of these rapid prototypes needed to be reinforced in the legs to acquire a rigid construction. These reinforcing constructions are not uncommon in existing chairs either: chairs often have legs that are connected with each other for rigidity. Sometimes by the use of tubular frames, sometimes by the use of reinforcing connections called stretchers or rails. Figure 30 shows the most promising outcome, chair legs connected to an added connection piece. This enhanced stability whilst being adaptable to the seat shape which is always different.

figure 29: explorative prototypes

figure 30: prototypes showing need for reinforcing construction of the legs

A: One loop

figure 31: concept A

4.3.2 Concepts
After pinpointing the need for a rigid and adjustable connection two main concept directions were produced. Assembling these two main concepts was a tipping point of the process: all required parts (seat, leg, comfort and styling) started to knit together.

Option A: 'One loop' (figures 31 & 32) is a concept direction in which one seat is printed as a single loop. In this manner, the loop of the seat (the two walls) serves as reinforced construction. At the same time, the loop of the seat communicates the uniqueness of the concept and by being able to look through the chair, it draws attention to the openness of the 3D printing process.

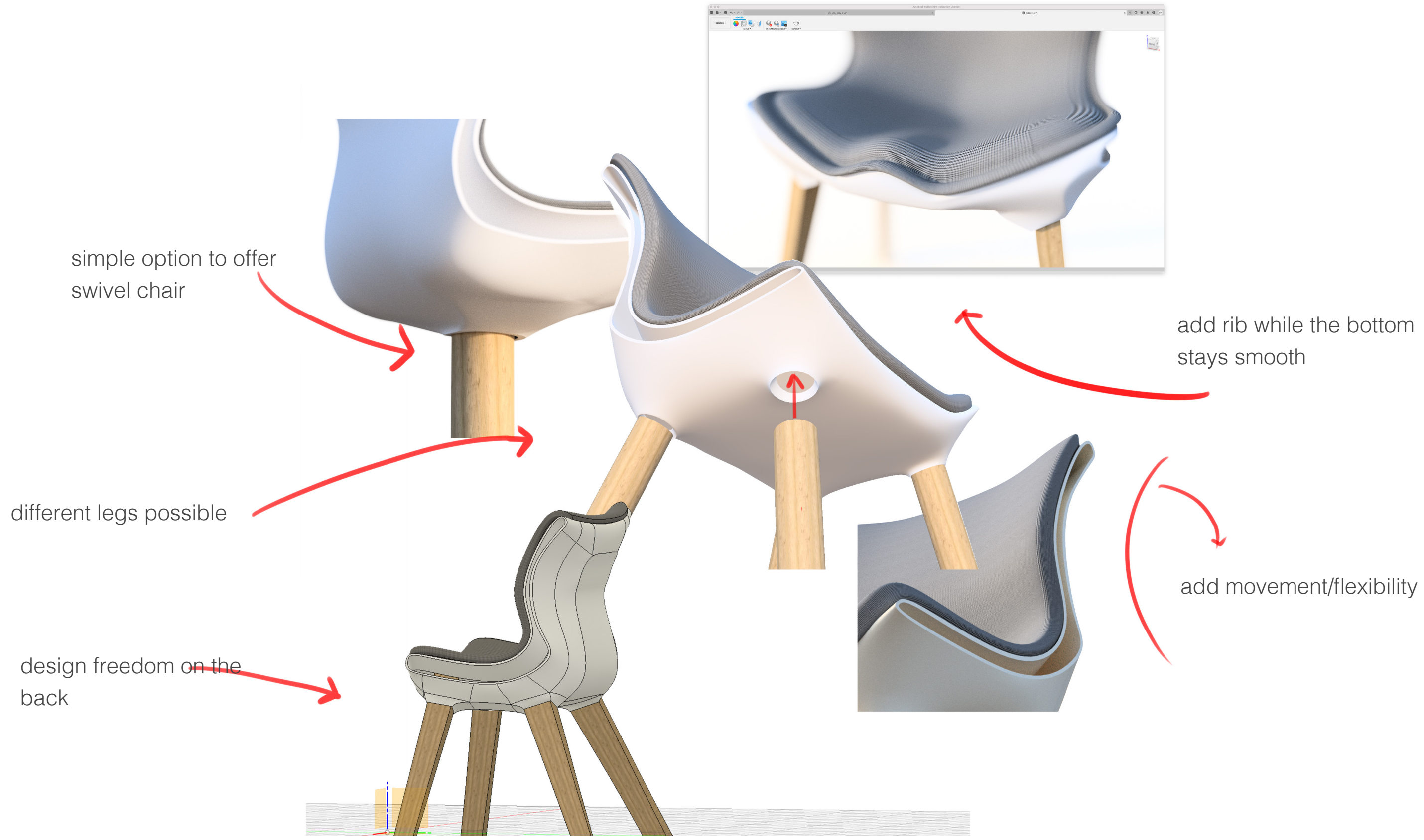

figure 32: possibilities for option A

B: Seat and connection

figure 33: concept B

Option B: 'Seat and connection' (figures 33 & 34) reinforces the legs by adding a separate connection part. As opposed to option A, multiple seats can be printed as part of the same print loop. The concept is visually less 'attention grabbing' and the narrative draws less attention to the manufacturing process, however, the result is more elegant and fits better with the archetypal chair and will therefore fit better in the home working scenario than the outspoken peculiarity of option A.

4.3.3 concept choice

As also seen in the ideation sketches (figures 32 & 34), both directions have multiple pros and cons. As concept A was limited to printing only one seat per loop, while concept B was a more elegant, solution, concept B was chosen as concept direction. Since the printing strategy, upholstery process have been settled upon, the following sections describes the development of this seat and connection piece direction.

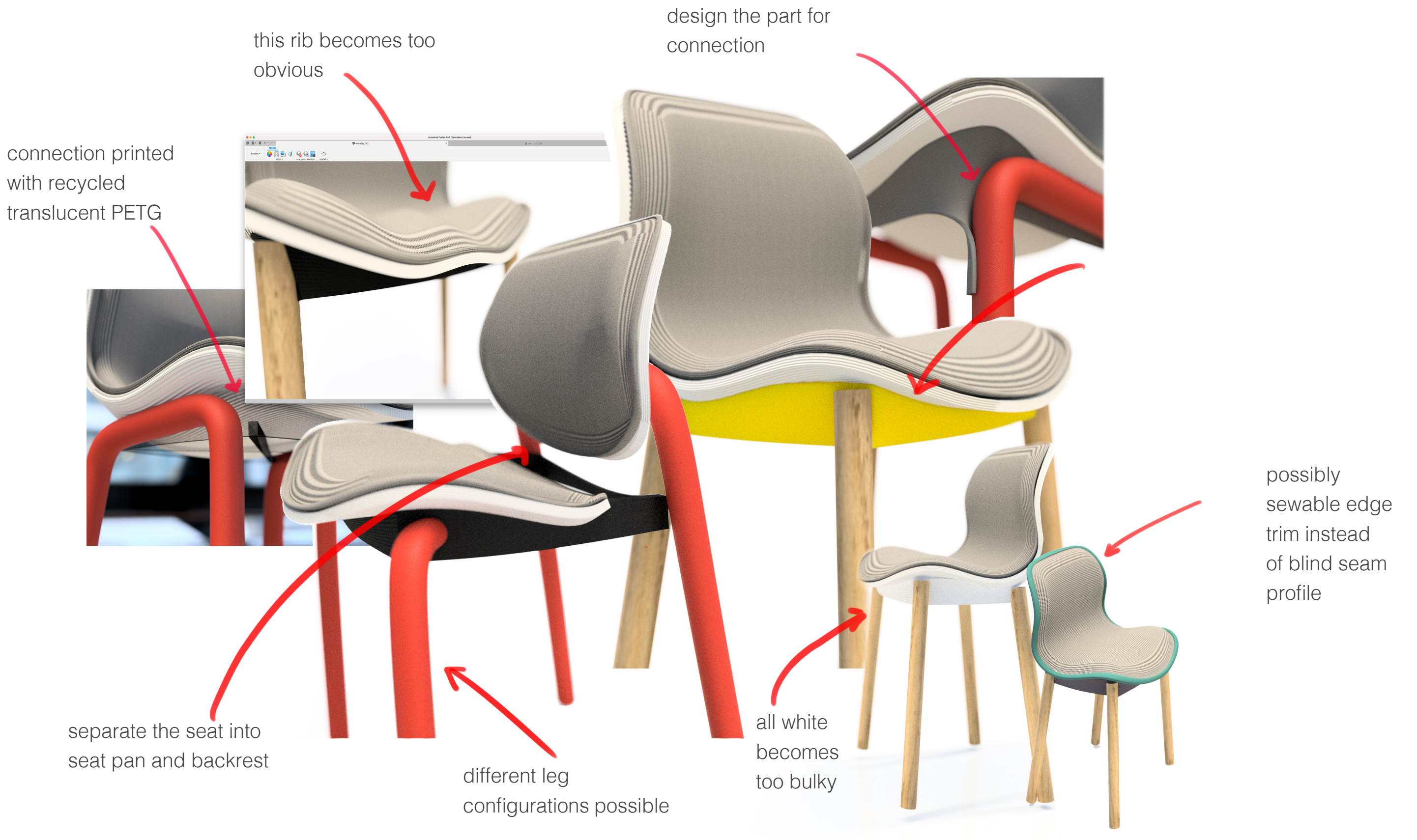

figure 34: ideation board with possibilities for option B

figure 35: three possible connection piece print orientations

4.4 Development of the connection piece

Just as in section 4.2, the printing of the connection piece could be addressed with various strategies. Figure 35 shows possibilities for print strategies.

4.4.1 Strength
As the material properties of 3D print are not equal in all directions, there is the opportunity to reinforce the entire design by orienting the two print parts in different orientations. The connection pieces of options 1 and 3 of figure 35 are oriented differently to the seat itself. In this manner, the direction dependent material strengths are combined to be stronger in multiple directions, like a laminated composite.

4.4.2 Connection
The connection piece and the seat need to be well fitted to each other. As the first and third variant in figure 35 are not the same printing orientation as the seat, the low resolution of the layers will not match. The middle option is printed in the same orientation as the seat, which makes sure that the two parts fit perfectly together.

4.4.3 Visual
Also the print strategy plays a role upon the visual impact of the chair. The first option has the most sturdy, but most standard appearance. The second and third option allow for a look through the chair (figure 36), which was an advantage of the disregarded concept A from the last chapter. Both options communicate the manufacturing process by showing the looped shape. Instead of creating bulky rigid walls beneath the seat, it creates a flowy open and outspoken character.

Because the second print orientation will ensure a pleasing fit to the seat, as well as it being visually the most significant, pleasing option, it was selected as preferred print strategy.

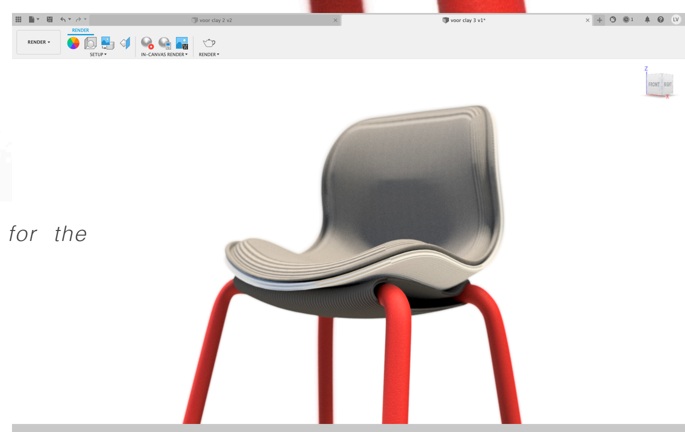

figure 36: chosen print orientation for the connection piece

figure 37: earlier version with rigid leg frame

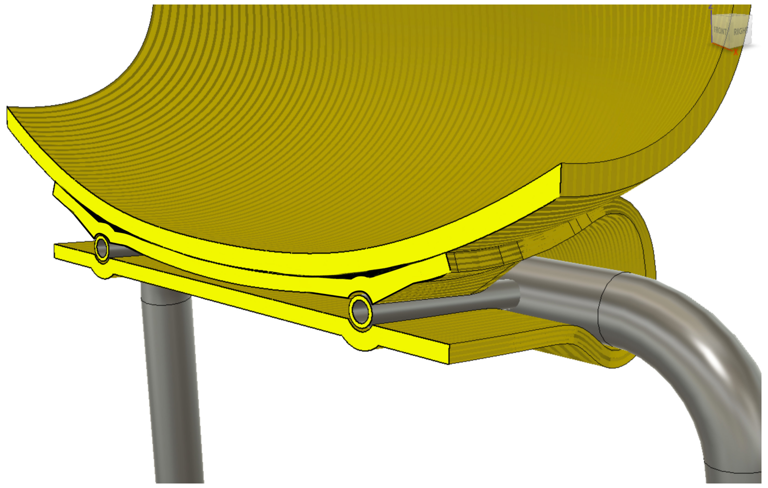

figure 38: cross section showing printed grooves

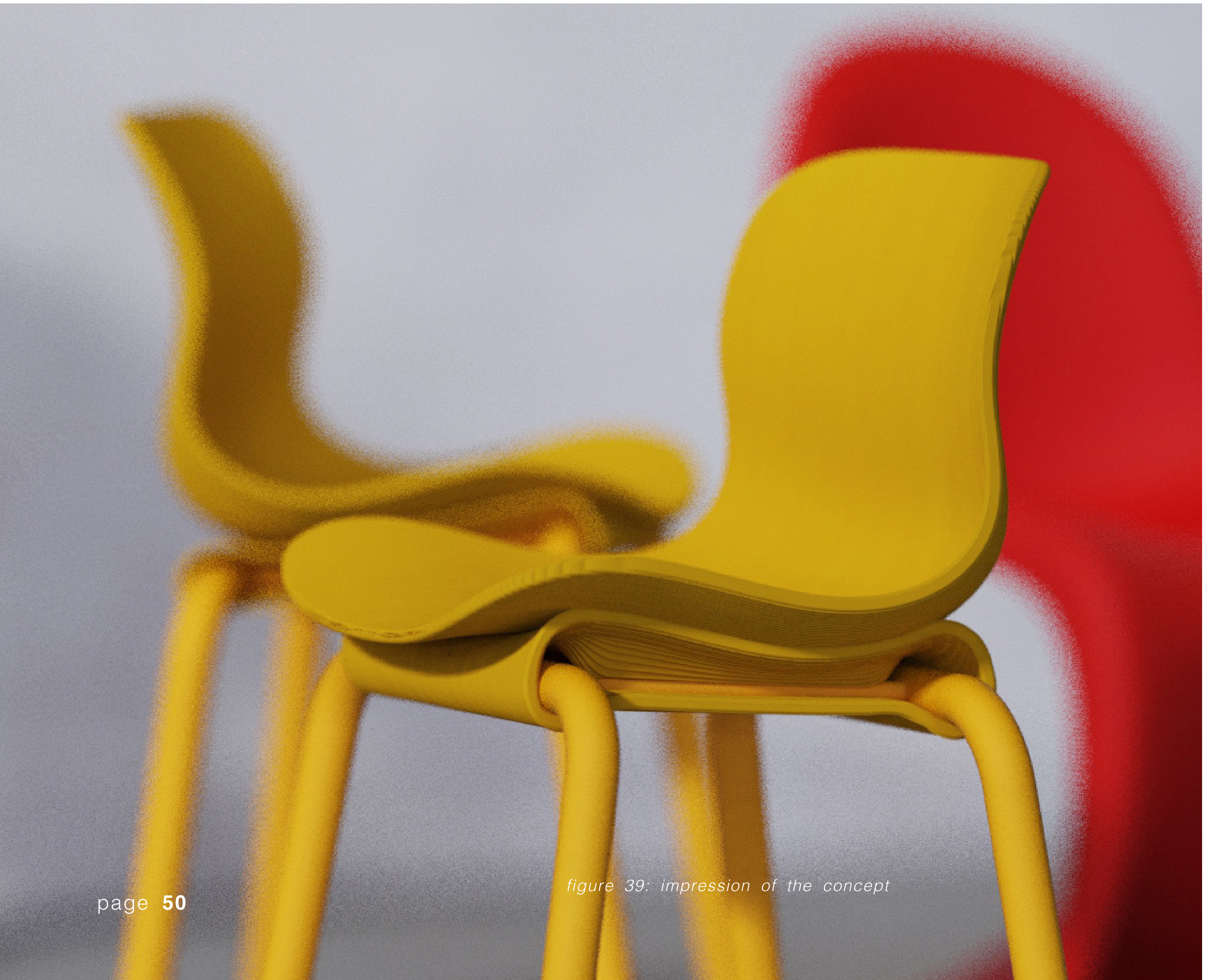

figure 39: impression of the concept

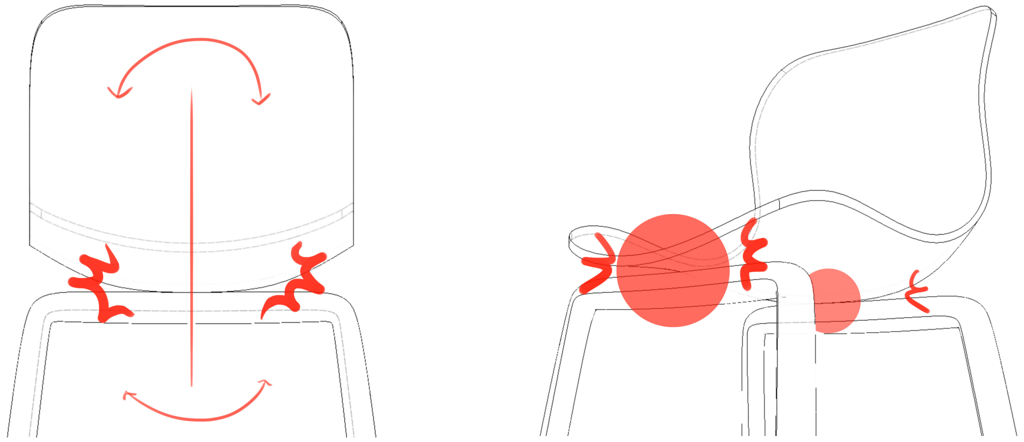

figure 40: illustration localized point load

4.4.4 Final concept

Theoretically, the chair is weakest between the print lines, in the final concept this is countered by making the legs go all the way through the frame. If the four legs were to be separated from each other, each leg would exert large amounts of stress on the plastic, making failure of the material more probable. By connecting the metal legs to each other (figure 37), the seat has a rigid base that does not exert additional force onto the material through the joints.

Finally, when the legs are going straight through the connection piece, the weight of the seat and user become a point load (figure 40), a tiny area where the straight metal tube and the lowest point of the curved plastic seat meets. The point load in this contact area has been avoided by printing grooves in the connection piece in which support beams are located, see figure 38. The support beams aid the load distribution. The final concept is seen in figure 39 and 43.

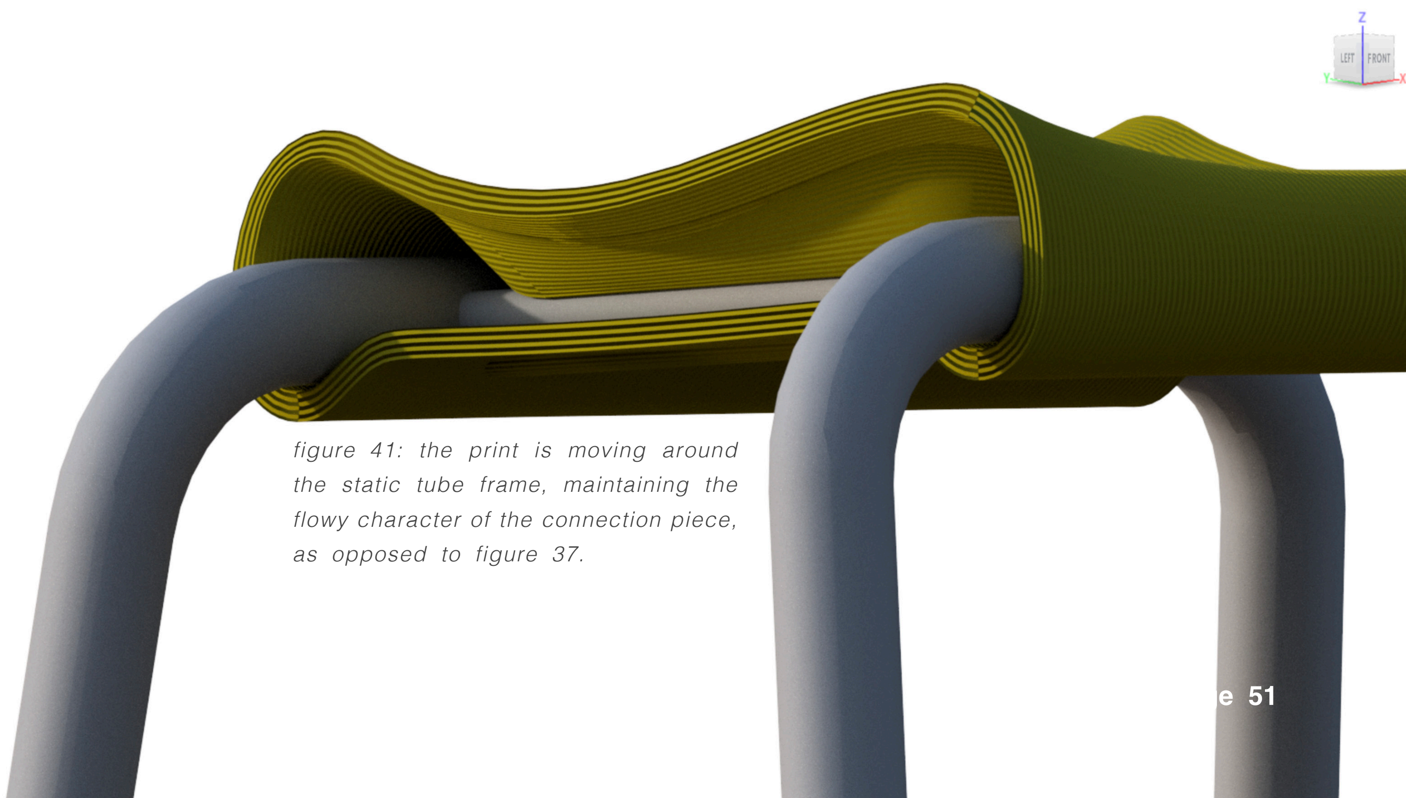

figure 41: the print is moving around the static tube frame, maintaining the flowy character of the connection piece, as opposed to figure 37.

5. Em-bodi-ment

5.1 Styling

This section describes how the concept can be turned into an actual product. Rather than an idea on a screen, it will be discussed and explained how it can be actualized. Materials, processes, tools and cost are discussed in this chapter.

A chair has been made in a certain way and with certain materials. Out of the thousands of available chairs, every chair is made differently and looks differently. A chair is not purely a functional object, it tells a story, it attracts the user. The styling of a product is a way of attracting the user or differentiating the concept. This is where shape, color, material and finishing come into play.

5.1.1 Narrative and design values

The concept presented in chapter 4 has been addressed in a functional manner and has resulted from the insights of the analysis phase. All these decisions and insights result in a specific value offering, one that combines DM with manual labor. Therefore these values should also be communicated in the detailing and product appearance. The moodboard in figure 42 shows the emotional narrative behind the concept: a chair that has been built combining the benefits, flexibility and independence of digital manufacturing techniques combined with the trustworthy, invested, caring qualities of manual labor. Focus lies on the opportunity and the interplay of these differences. The rough imperfect texture of 3D printed material is an asset instead of a hindrance and is complimented by a rough woven fabric.

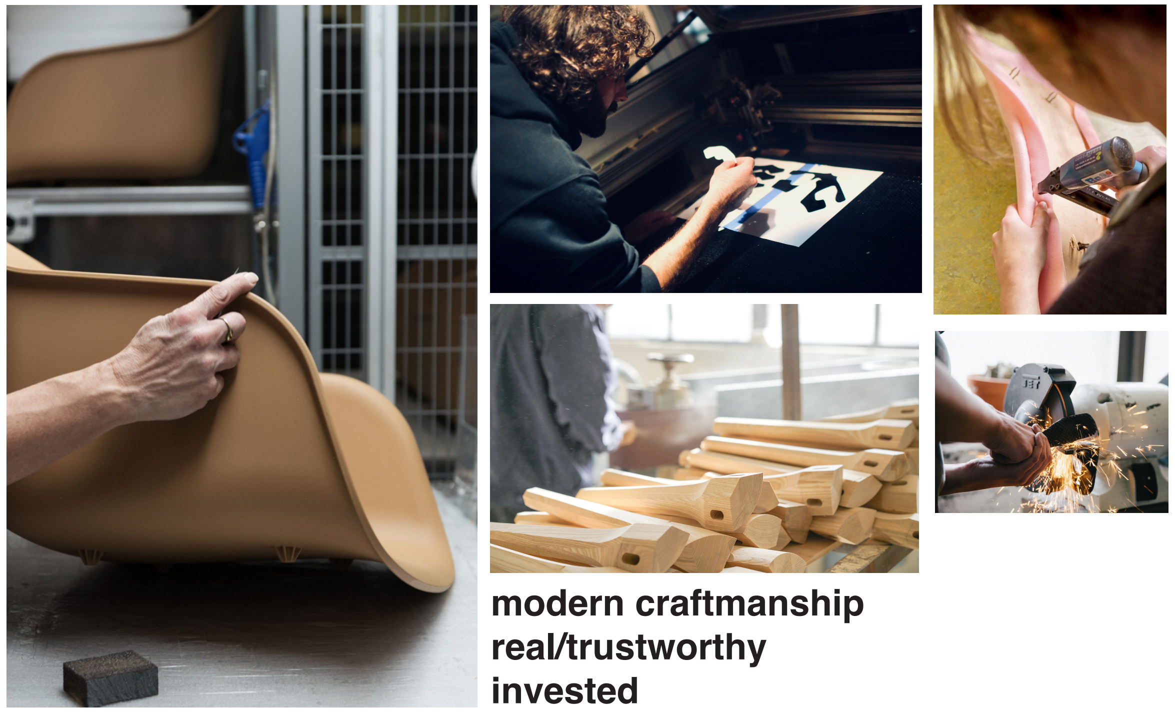

figure 42: narrative moodboard

5.1.2 Visual inspiration

Apart from the emotional narrative of figure 42, the figure 43 describes a more literal approach to the styling and detailing. Since the targeted user, established in section 3.7, tends to be a more younger urban home worker, the imagery was chosen to be more bold, cheeky, and modern. Within the moodboard, these characteristics are expressed with thick and strong shapes. Straight, geometric shapes combined with friendly curves as a metaphor for the combination of digital and manual labor. The pronounced textures also emphasize the manufacturing techniques combined with fresh, accessible color combinations (more on texture and color in section 5.1.9).

figure 43: styling inspirational moodboard

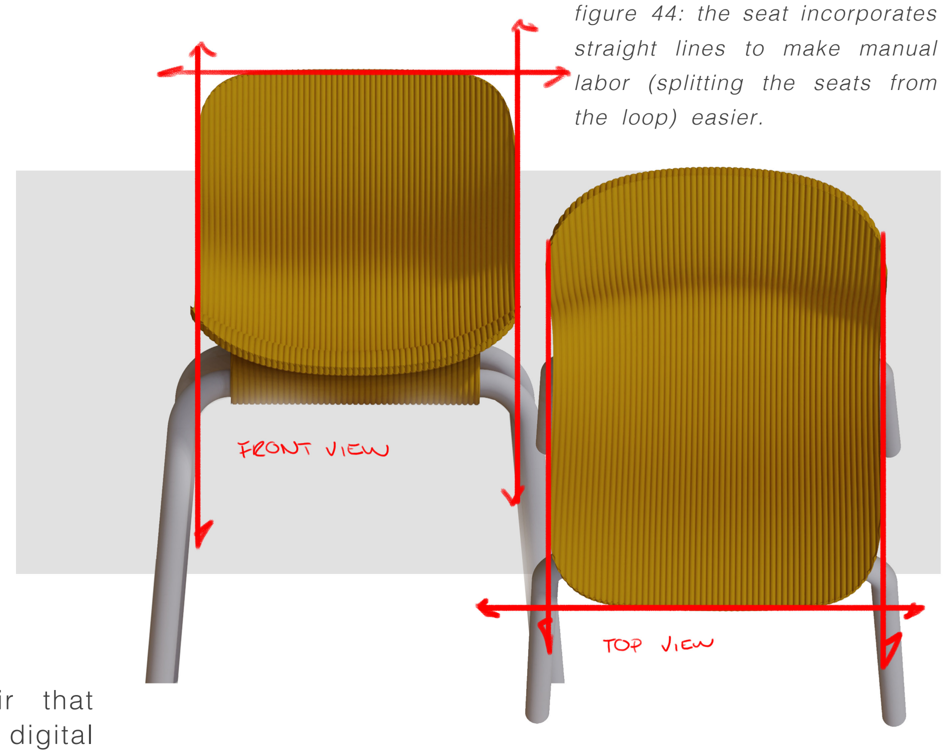

figure 44: the seat incorporates straight lines to make manual labor (splitting the seats from the loop) easier.

5.1.3 Seat shape

Getting the right seat shape was a gradual process, which slowly developed during prototyping. For more insights in how the shape of the seat was developed, see Appendix I. The shape of the seat should also emphasize the narrative of the design: a personal, comfortable chair that was manufactured combining digital and manual labor. This is manifested through the fluent curvature that is a result of the numeric controlled printer. This is contrasted with the straight edges of the chair, figure 44. These straight edges are not just for visual contrast, but are also an result of the manual labor because the seats are sawed from the loop with a band saw, resulting in straight edges.

5.1.4 Curvature

The smooth curvature results in a friendly, inviting shape. Especially the smooth curvature in the buttock area and lumbar support possess a comfortable accessibility. However, the curvature has been emphasized slightly to look more balanced and to look more comfortable.

For instance, the curvature in the thigh area should be less pronounced than in the back area. See figure 45. Still, the visual balance was also considered to be important, therefore the curvature has been extended to the thigh area as well. It would be advisable to keep considering the trade-off between a more visually balanced and beautiful chair, or a more exact and ergonomic one. Since the goal of this project was to design a subjectively beautiful chair for the home working scenario, it was decided to let visual balance be important as well. Whether this consideration was just, should be critically evaluated. The modeling strategy for capturing the smooth curvature is described in section 6.2.

figure 45: from left to right, the seat shape increases in visual balance and flow, while becoming less accurate

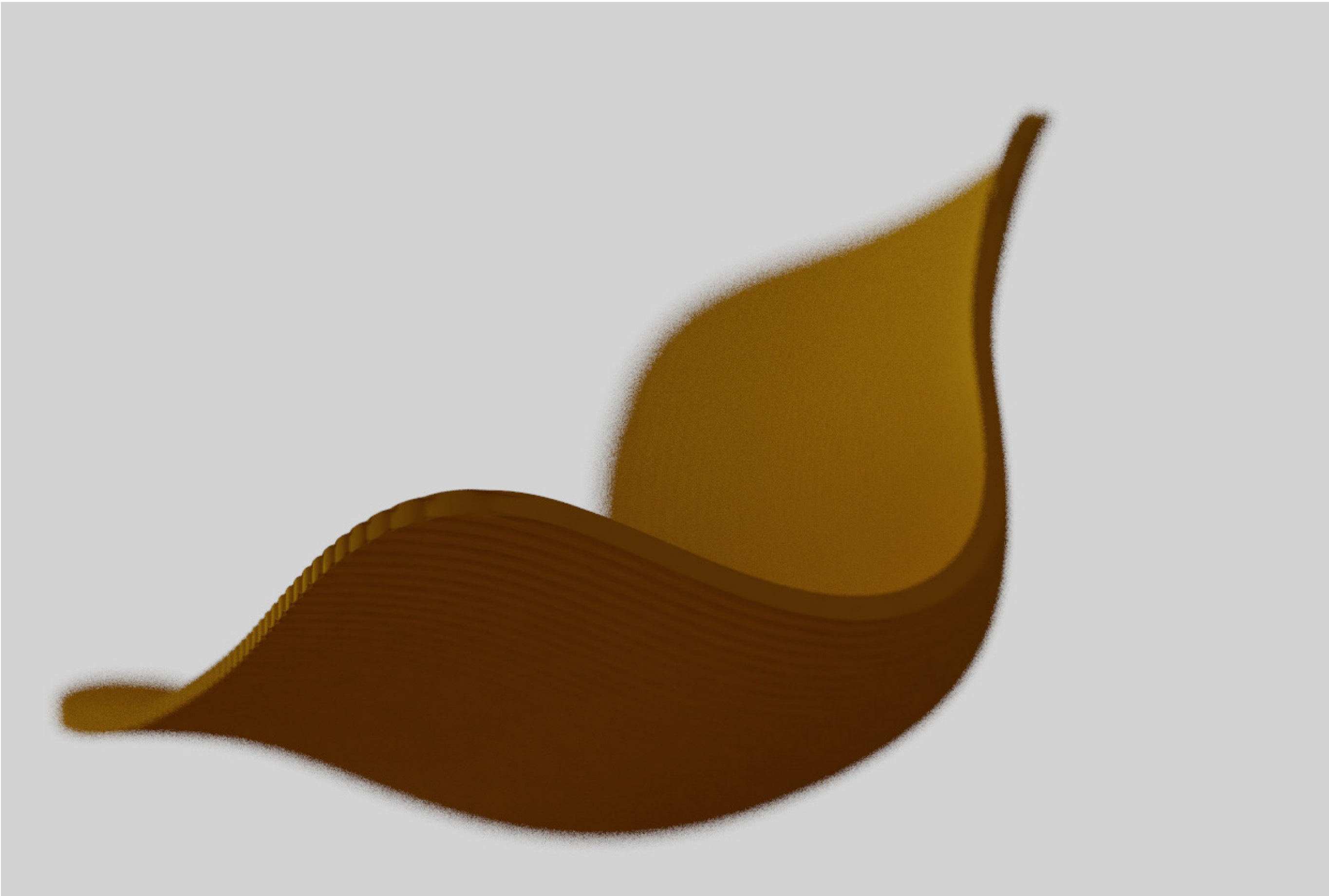

figure 46: render of the final seat shape

5.1.5 Upholstery

The blind seam profile is the preferred method for upholstery for two reasons. First of all, since the fabric only covers the front of the seat, instead of going around the edges, results in a thinner looking chair. Secondly, since this method only covers the inside of the seat, the outside is left unclothed, showing the 3D printed lines as an aesthetic statement.

The thickness of the foam is also a trade-off, where 30 millimeters of foam was found to be most comfortable (section 3.8), but thinner foams make the product look more lean and therefore 20 millimeters of foam was chosen. For visual comparison, see figure 49.

5.1.6 Legs, stance and bends

The tubular frame possesses a straightness and boldness that contrasts the fluent qualities of the seat. Through modeling and digital sketching, the frame was made to look bold and cheeky. Various leg stances, tube thicknesses and bend radii were considered, see figures 47 & 48.

5.1.7 Texture

As a tribute to the wonderful technology of 3D printing, the printed lines should be visible. Through modeling, textures with various layer heights were tried. The options with a line height of four to six millimeters were most pleasing. The rendered examples of the various layer heights can be seen in Appendix J. Due to the preferences of 3DRP, where the prototype was built, 4 millimeters proved to be a good starting point for the prototype, more on that in section 6.4. A visualization of this texture is seen in figure 50.

For the fabric, also a rough weave was chosen (figure 51). This was to emphasize qualities of manual labor. Instead of a perfectly smooth spandex-like fabric, straight from the factory, the coarse weave has a more outspoken character.

5.1.8 Sizing

In figure 52, an illustrative size comparison between the design, a dining chair and a office chair is made. The seat was sized to be small, as that is one of the value offerings of this concept. This also means that there was a trade-off between size and ergonomics: the seat is relatively small to be visually balanced. This means there will be less back support compared to office chairs. Whether this was the right decision should be critically evaluated.

figure 47: overview of possibilities with industry standard tube diameters and bending radii.

figure 48: side-view stances

figure 49: 30mm of foam (left) compared to 20mm of foam (right)

figure 50: 4mm layer-height, 10 mm wall thickness

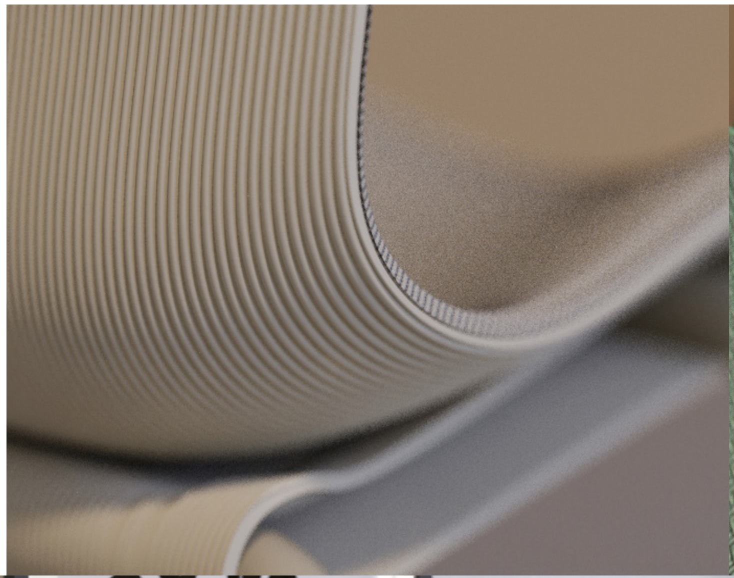

figure 51: a rough weave combined with the blind seam profile

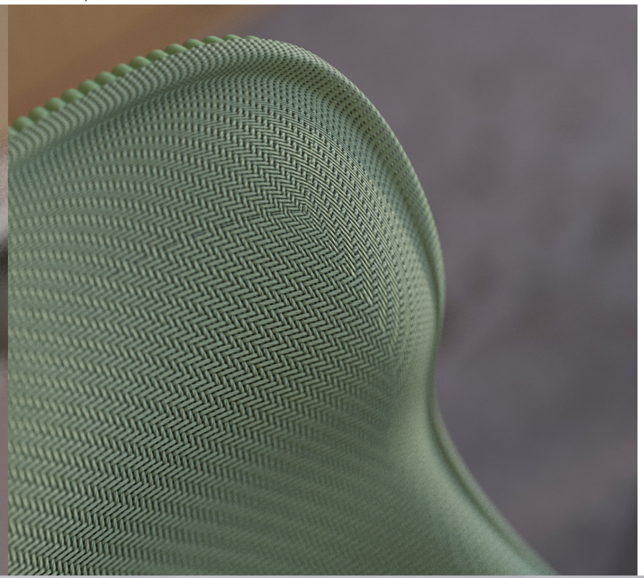

figure 52: size comparison

coopi: 5. embodiment

figure 53: example of combination of color-ways

5.1.9 Color strategy

Fresh and trendy colors fit best with the scenario and the narrative of the concept. Yet, it is impossible to choose one or two colors and simply assume it will fit into every interior. Also logistics need to be considered, therefore it would also be impossible to offer a infinite range of colors. The chair-legs may become the bottleneck, as the frames will be produced at three sizes (more on that in section 5.3). Any color added to the product line adds three additional stock keeping units. Whereas the printing and upholstery process will only start after the order is placed, the color of the granulate and fabric can easily be interchanged. The legs need to be purchased and stored, so it would be best to keep a lower number of colors. For example two to four leg colors combined with a larger number of print colors and textiles. This gives the user an extra customizable feature which fits the design philosophy, as well as an extra opportunity to adjust their product to their liking and surroundings. An example of color combinations can be seen in figure 53. The Coopi being composed with two colors also visually contrasts the legs from the 3D print: visually emphasizing the movement of the legs going *through* the printed connection piece.

For the final color strategy, extra research could be done regarding the latest color trends and marketing considerations.

5.2 naming and branding

5.2.1 Chair naming
The bold, cheeky, outspoken character of the chair deserves to be named. Naming the concept is a testimony to the uniqueness of the manufacturing process and the design itself. It will be no surprise that the name Coopi was chosen after some ideation (different options can be seen in Appendix K). Coopi was chosen to sound friendly, yet strong and catchy. The name is obviously aimed at the customization of the concept (a nod to the word 'copy'), while the logo hints at the manufacturing process and character of the design.

5.2.2 Logo
As in figure 55, the logo for Coopi is presented. The characteristic merged "oo" hints at the looped printing of the connection piece. The bold, geometric yet curved typeface grasps the characteristic design and resembles the fatness of the 3D print and the outspoken boldness of the legs.

5.2.3 Individual naming
The overarching name of Coopi describes the concept and the product line. However each chair is different, so each chair is a different model. *Coopi for Leon, Coopi for Koen* or *Coopi for Eliza* stretches the personal nature of the concept. The chair is not only printed for you, it is even named after you, see figures 54 & 55.

5.2.4 On-product branding
The product will be marked with a sew-in label. As the upholstery process is of manual nature, this has been emphasized by handwriting the name of the user on the label. See figures 54 & 55. This personal touch should remind the user that the Coopi has been produced for them personally and will hopefully enrich the user's emotional connection with their chair. Handwriting the name of the user on the packaging could also be an option to enrich and personalize the unboxing experience.

figure 54: prototype for the on-product branding

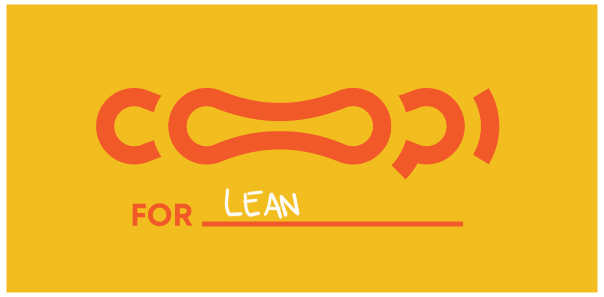

figure 55: handwritten tag

figure 56: coopi logomark

5.3 Leg frame

Bending the tube frame for the concept should be outsourced. Suppliers with mandrel tube bending machines are preferred. During the mandrel bending machine, the inside of the tube is supported with a flexible part: the mandrel. This supports the inside of the tube while bending, resulting in a smoother (non wrinkly) bend and a smaller bending radius. Whats-more, mandrel bending machines are also CNC operated, meaning that the production of three frame sizes does not require large additional investments for molds and such. Suppliers often operate with industry standard tube sizes and machine limited bending radii. For this design the standard tube diameter of 33,7 mm and a bending radius of 60 mm was selected based on the capabilities of a local tube bending supplier.

5.3.1 Three size frame

In product design, it is common practice for products to be aimed at the average user. Think of desks, dining chairs, toilet seats: if properly designed, the average user will fit well onto it. However, these products are not optimized for the smaller and larger users. They might still be able to use the product, but do not experience the perfect fit as intended. Adjustable desk chairs add options for mechanical adjusting to fit 95% of the population equally well (it fits a P5 female as well as a P95 male), without compromising the feasibility. Now, logically a 3D printed seat could range to meet more than 95% of the population. However, the concept is limited by the tubular frames, which cannot be adjusted in width and length, but only in height, as they will be manually shortened. Offering an infinite range of tubular frames becomes infeasible, so a strategic decision has to be made.

Does this concept really need multiple frame sizes? For the sitting experience, one frame size would suffice as the seat itself will be scaled to the human body, and the (popliteal) height can be changed by sawing the tubular frame. The seating experience would therefore be unaffected. However, in that case the product would still become a product that is optimized for the P50 user. In figure 57, examples of various extremes are shown: the odd combination will lead to functional, but less desirable products. In figure 58, the same user size variations are shown, but with three frame sizes. This shows that it is relatively easy to offer improved products to (almost) all users by only introducing two additional frame sizes, rather than offering a product that once again, is aimed at the average user, disregarding the largest and smallest users. Figure 58 leads to believe that no more than three sizes would be necessary, this has been based on size variations from P0.1 to P99.9, see figure 59 (DINED, n.d.). However, this size variations are only accounted for the Dutch population. Depending on the business case of the client, if the concept would be introduced to other markets, the dimensional ranges would grow.

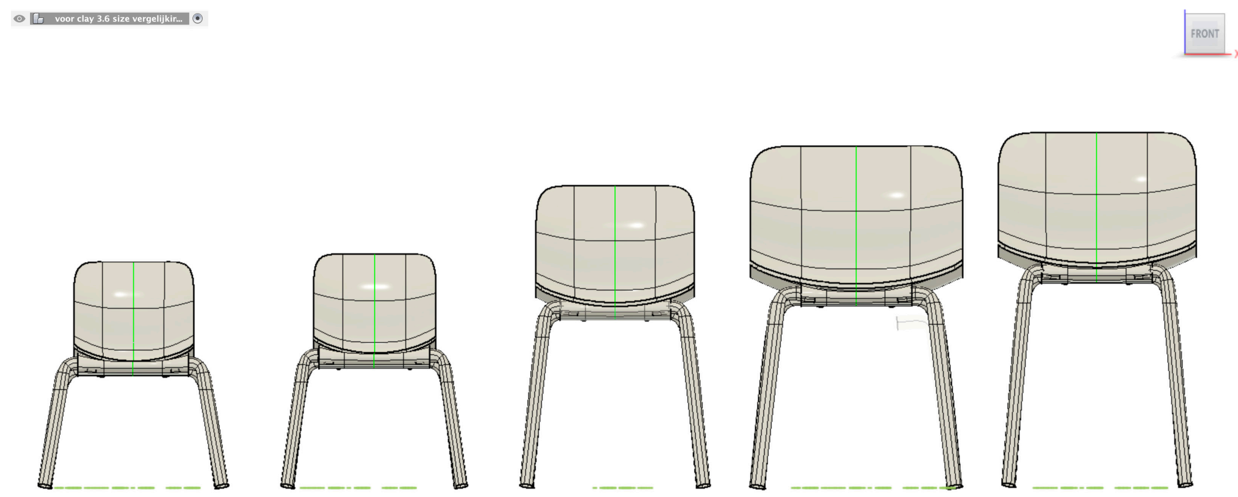

figure 57: p1 female, p1 male, p50 male, p99 female, p99 male with one frame size

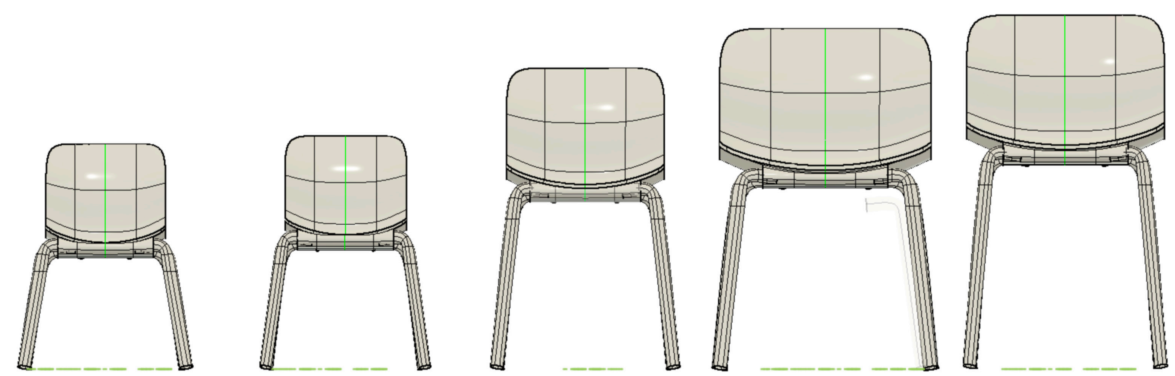

figure 58: p1 female, p1 male, p50 male, p99 female, p99 male with three frame sizes

populations	Dutch adults 31–60, male			Dutch adults 31–60, female		
measures	P0.01	P50	P99.9	P0.1	P50	P99.9
Hip breadth, sitting (mm)	300	397	477	318	414	510
Buttock-popliteal depth (mm)	403	503	586	416	499	582
Popliteal height, sitting (mm)	362	481	580	354	434	514
Body mass (kg)	37	82	119	36	70	104

figure 59: dined data comparison Dutch adults 2004

coopi: 5. embodiment

5.4 Production process

Over the previous sections, it was described why the concept is as is. This section will describe the process for manufacturing.

5.4.1 Print and optimization
To spend the print time effectively, multiple seats are printed within a loop. The exact number of seats that can be printed within one loop is dependent on the optimization of the printing setup. When building a prototype at 3DRP, see chapter 6, two seats were printed within a loop, see figure 60. This happened at a printing speed of only 19 millimeters per seconds, while at different scenarios, the setup can print at a speed of 150 millimeters per seconds, hinting at the room for printing more effectively.

5.4.2 Separating the part from the loop
The loops contain the seats and connection parts, but those need to be separated, visualized in figure 60. This should be done manually with a band saw. Also the rounded corners have to be cut out from the loop. This can either happen with band-saw or jigsaw.

5.4.3 Finishing
Band-saws and jigsaws are capable of smoothly cutting the material without splinters and tear outs. However to guarantee clean curvature, a disc sanding machine helps to smooth the rounded corners. After cutting and sanding the part into shape, the edges are still sharp and can be rounded off with a hand router. Finally the last manual operation for the seat and connection piece is to drill holes and insert threaded inserts which are used for assembly later on.

5.4.4 Inspection
Before spending materials and labor hours on upholstering a defective seat, it would be advisable to do an initial quality control. The seat should be tested on symmetry, endurance, static load and visual inspection of print and finishing quality. A quality check can reduce risks of repairing/replacing defective products, as well as reducing risks in immaterial damages to the brand reputation.

5.4.5 Upholstery
The upholstery process is the most labor consuming part of the manufacturing process. Since every seat is unique, foam and textile need to be fitted and assembled by hand. For this process, a trained upholsterer will be needed. For the upholstering process, a foam cutter, pneumatic tacker and sewing machine are needed.

5.4.6 Shortening legs
Shortening the legs of the three sizes metal frame can easily be done with a cold saw.

5.4.7 Packing up
As a final step, all manufactured parts should be inspected and all manufactured and purchased parts should be packed, ready for delivery.

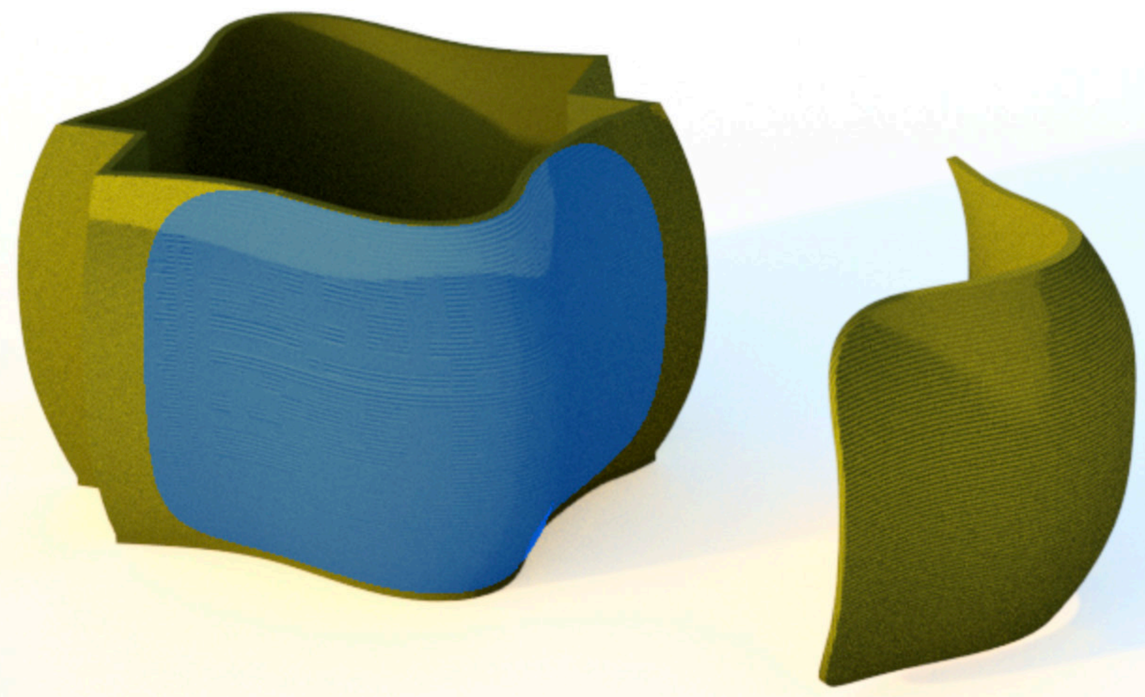

figure 60: example of a loop that contains two seats

5.5 Assembly at home

Whether or not Zon&Hoofd wants to give the customer the opportunity to see the product in a physical brick-and-mortar store, should still be decided upon. However it is likely to assume that customers are not picking up a fully assembled chair, as they are never in stock, the chair is only made after the order is placed. The Coopi is sent home, unassembled: to make shipping cheaper and more responsible. The assembly process was envisioned as seen in figures 61 & 62.

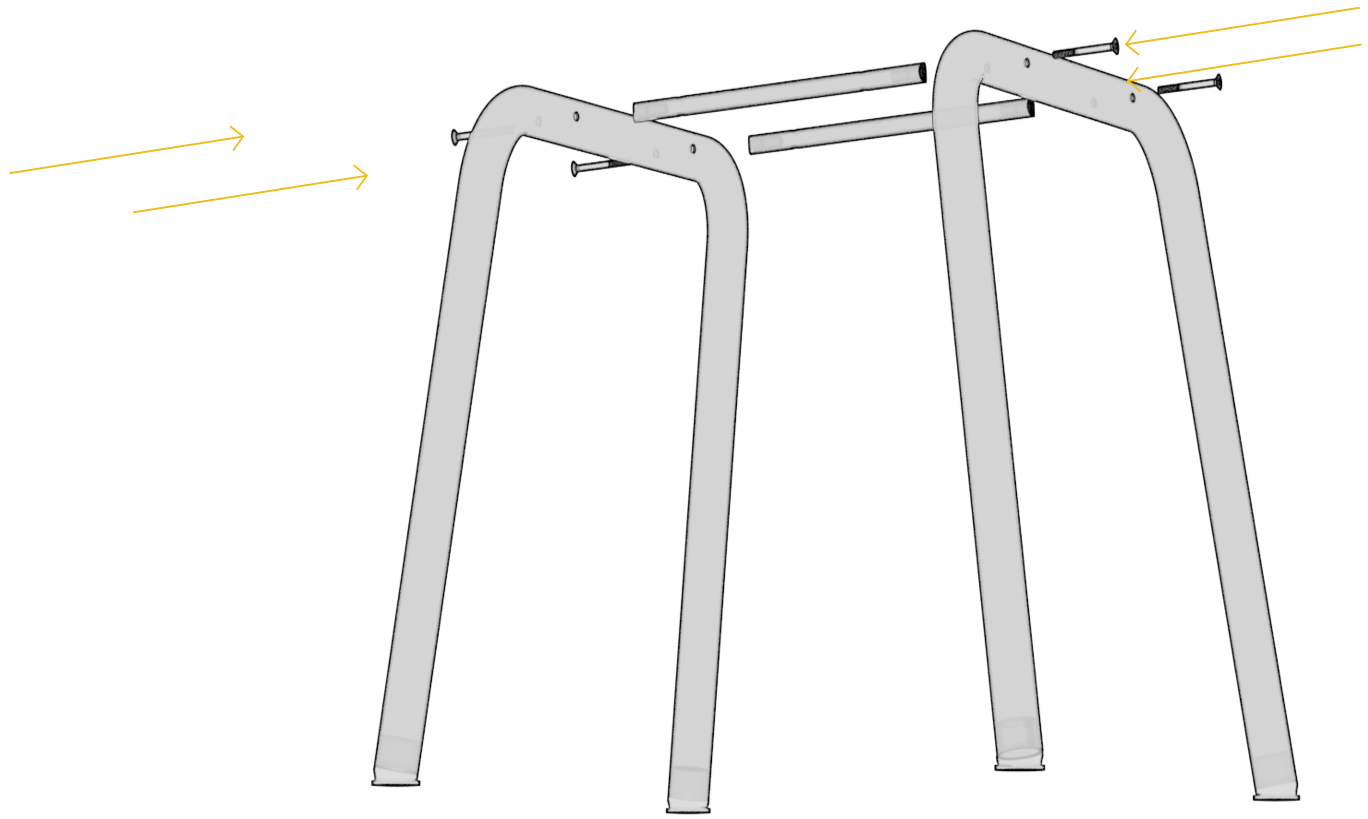

figure 61: assembly of the frame

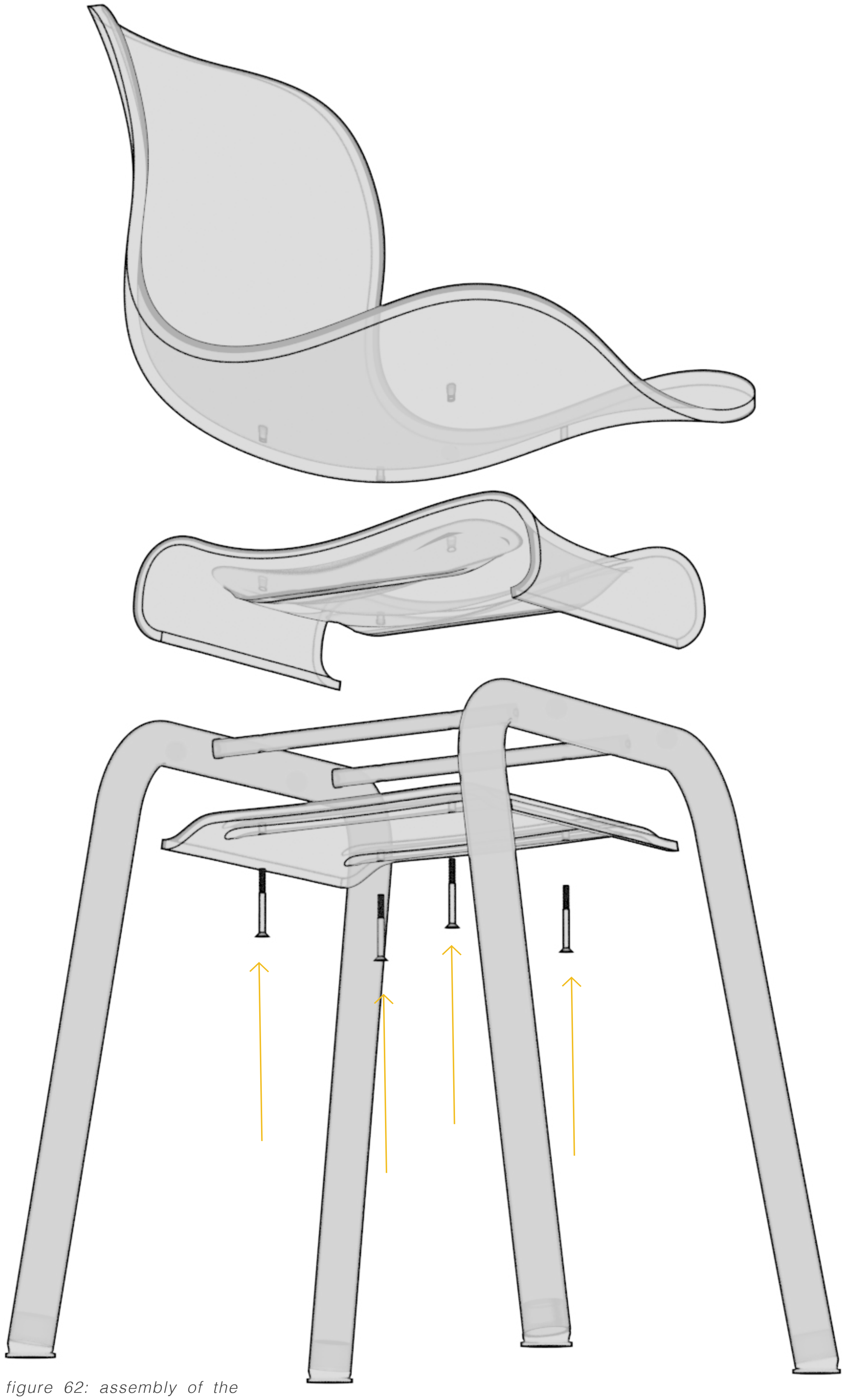

figure 62: assembly of the

5.6 Price estimation

When validating the concept, it is concluded if the monetary value of the concept matches the perceived value by the user. Obviously, the concept should be produced at a manufacturing cost that results in a sales price that can match what the user is willing to pay, while also being profitable for the company. To already name an exact manufacturing cost will not be possible until actually starting up the production process, but an estimation helps in validating the concept.

Printing time: during prototyping (chapter 6), the printer took around 100 minutes to print two seats. While the printer needs these 100 minutes to reach the desired height (remind you of the minimal layer time), the scenario could be optimized to print three (or perhaps even four seats) within those 100 minutes. Let's assume an optimized scenario where three seats are printed in 100 minutes and three connection loops are printed in 75 minutes (the connection pieces are only 75% the width of the seats). This would result in a total printing time of 59 minutes per product.

The manual labor for finishing and assembling the product is estimated at 20 minutes, the quality control and packaging at 5 minutes, while the upholstery time, in an ideal situation, is roughly estimated at 45 minutes.

An estimation for the cost of required material and components (figure 64) can be seen in figure 63, which indicates a total of €66,78. When we estimate the impact on manufacturing cost of the manual labor (€25/hour) and machine cost (€40/hour) it adds €69,- to the manufacturing cost. Resulting in a rough estimated total of €135,78. As the sales price will typically be four times the manufacturing costs, this would arrive at the preliminairy sales price of €543,12

Investments
The manufacturing price named above includes material, components, labor, machine cost, packing and quality inspection. However for this concept to be realized, additional investments need to be done, think of developing the tools for obtaining the anthropometric data, the development of the parametric CAD model that generates the individual chairs, investment in machinery or marketing.

Main variables
Concluding, a first estimation of manufacturing cost and sales price can be made. With this estimation, it is worthy to note that these are ideal scenarios, in which costs are kept low by optimizing the process. For example, the cost of outsourcing the printing (estimated [confident]) is higher than the estimated cost of owning and running a machine per hour (€30 - €40) (Tempelman, 2021). When it comes to raw materials and prefabricated components, there would not be a large variation in cost price based on the business model. For example: a chair needs a layer of foam regardless of the business proposal. Or: the chair could be made a couple grams lighter to reduce the material cost, but this would not make the biggest difference. Where the main variable lies, is with the printing cost, as the amount of seats within a loop (now estimated at 3) or the cost per hour of printing can really make a large impact on the manufacturing costs. The client is advised to critically research their business model with this in mind.

part	Estimated cost	amount	total cost
Glass fiber-reinforced polypropylene	€4/kg	4 kg	€16,-
Polyurethane HR 45 20mm	€6,50/m2	500mm x 700mm	€2,28
Textile Kvadrat Hallingdal 65	€75/1000mm x 1300mm	500mm x 700mm	€25
Seam profile	€0,40/meter	2,5 meter	€1
Frame	€15	1	€15
Fasteners: bolts, threaded inserts, washers	€2		€2
Sew-in label	€0,50	1	€0,50
Tube feet	€0,50	4	€2
Packaging, protection and instruction	€3	1	€3
Spray glue, staples	€0,20		€0,20
			€66,78

figure 63: BOM

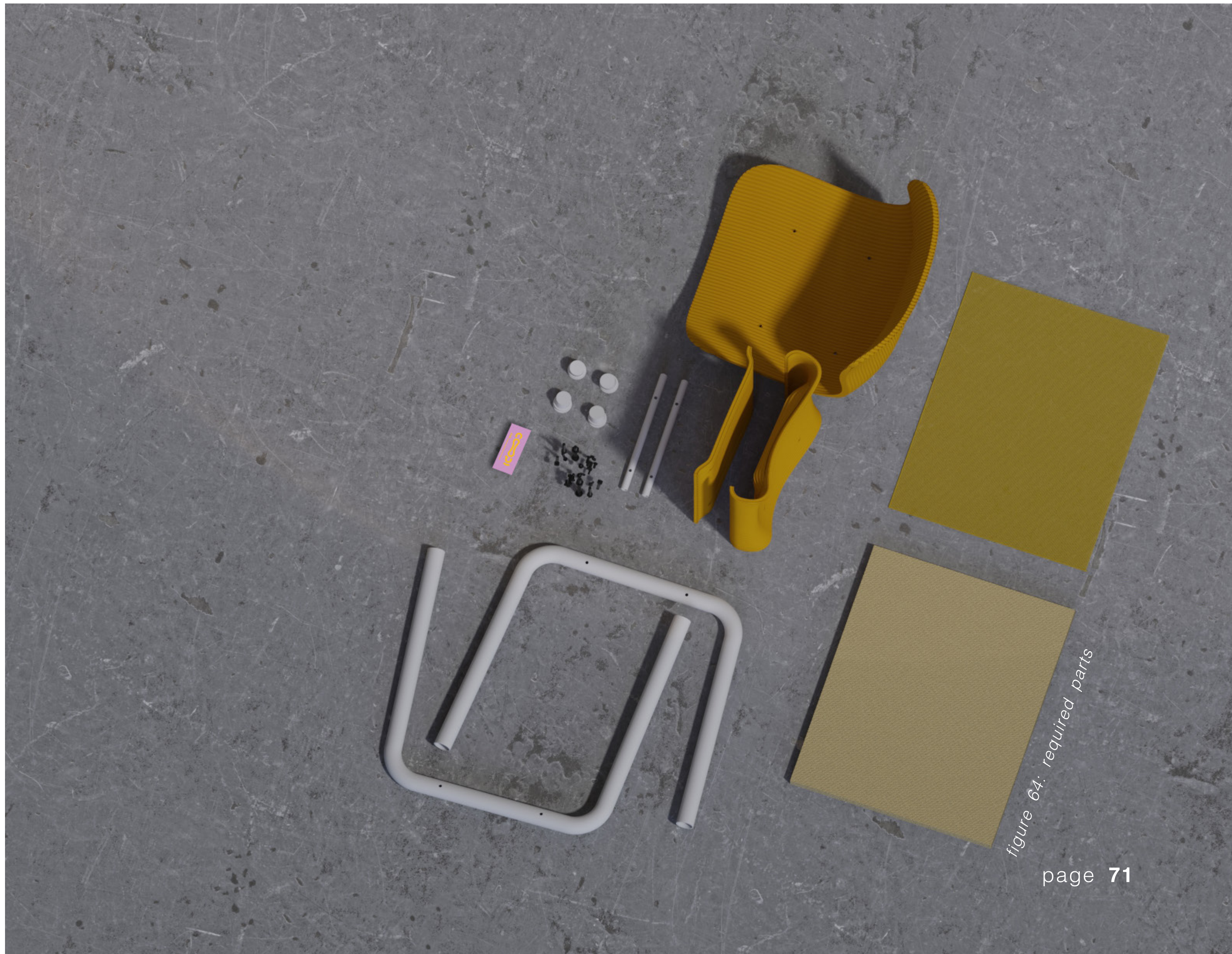

figure 64: required parts

5.7 Product presentation

6. Pro- totyp- ing

Prototyping

A prototype is not just a gimmick, to show off. First of all, a design that solely exists in the virtual 3D environment cannot be assessed the same way as a real 1:1 product can, by prototyping, the actual impression can be assessed. At the same time, this should not only be a visual prototype, but a functional one as well. By building a chair that can actually be used, the comfort and ergonomic experience can be assessed and suggestions for improvement can be made, something that simply cannot be done in the CAD environment. Thirdly, the process of building the prototype will teach about the feasibility of the concept as is. Are the steps necessary to build the product as easy as proposed? Is the material strong and stiff enough? Is the finishing or assembly process as expected? By actually building, various unforeseen circumstances can pop up and suggestions for improvement can be made. Lastly, delivering a presentation model can serve as a tool for marketing research, something that will fall out of the scope of this project, but will be valuable to the client.

6.1 Obtaining anthropometric data

To build a physical model and to tailor this model to a user body, anthropometric data is needed. This could have either been done by measuring the human body or by 3D scanning. 3D scanning was preferred, as its results are immediately and accurately presented in the 3D space, without need for interpretation of the measurements. For this process, an imprint in a vacuum chair (see figure 65 & 66) was 3D scanned.

6.2 Modeling software

For developing the model, Autodesk Fusion 360 was used. Fusion 360 is a flexible CAD software that offers multiple modeling strategies which makes it easier to combine a solid model and the 3D scanned mesh together. The fact that software such as Fusion 360 or Solidworks both offer parametric solid and surface modeling seems to be a big advantage for the final product 3D model generation. However during the modeling process, it shows that the bezier capabilities are limited. Parametrically adapting bezier curves caused a lot of errors: it is doable to build a fluent product like the Coopi from scratch, but the software is not that great for changing the inputs and adapting the curvature of the model. Since Rhinoceros, in combination with Grasshopper, is known to be powerful when it comes to parametrically designing organic curves and patterns, it would be advised to build the final adaptable model in Rhinoceros and Grasshopper. For the prototype, Fusion 360 sufficed.

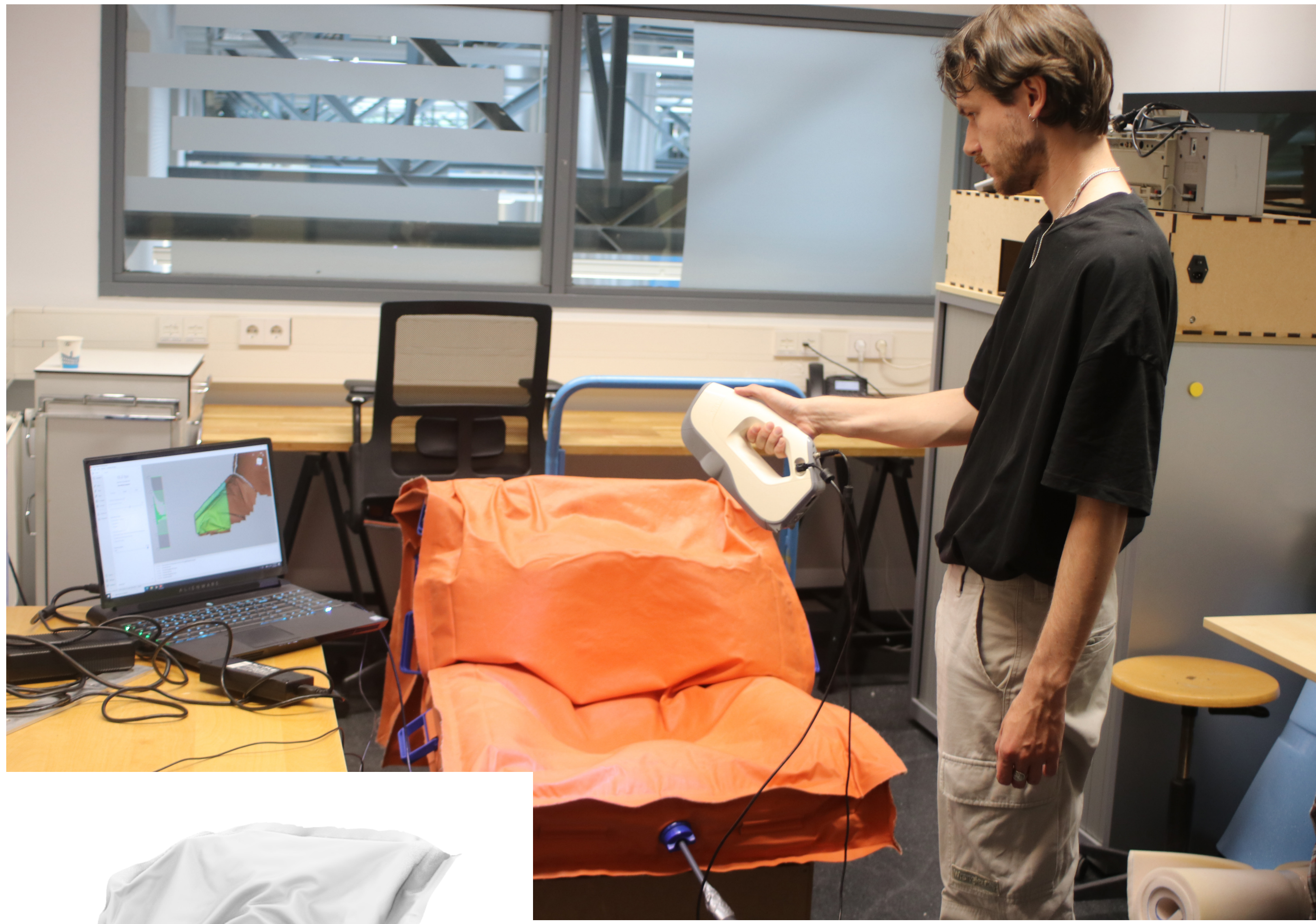

figure 65: example of a vacuum chair

figure 66: resulting scan data

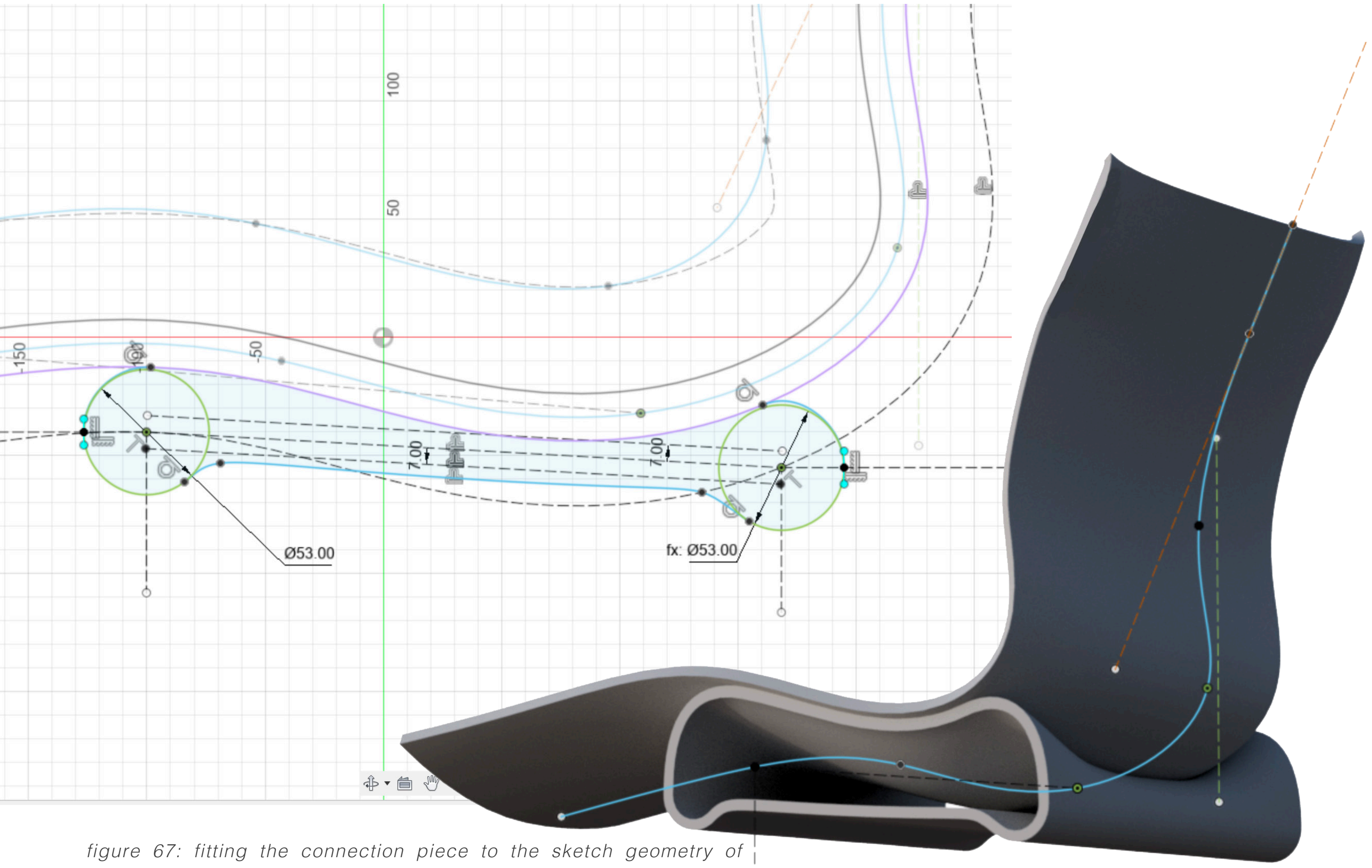

figure 67: fitting the connection piece to the sketch geometry of the seat

6.3 Modeling strategy

The CAD model has been made by lofting five bezier curves/splines, see figure 68. Of these splines (splines have the same curvature result as bezier curves, but offer more control in the CAD workspace), each spline has eight knots, found to be the necessary amount for creating the needed shape, whilst maintaining the smooth curving qualities. After lofting the five curves, the connection piece was modeled to fit the exact splines, as can be seen in figure 67. It was chosen to loft a longer shape first and cropping the seat afterwards, see figure 69. This was done to ensure curvature continuity and to make it easier to place the 3D-seats into a loop that can be printed. Especially shaping the connection piece, to properly fit the seat (figure 67), is what the software struggled with. Anytime the seat changed its shape, the connection piece broke and had to be remodeled. For a valuable business proposal, a flawless adjustable CAD model should be made. For this prototype, matching the lofted curves to the 3D scan data resulted in a smooth surface.

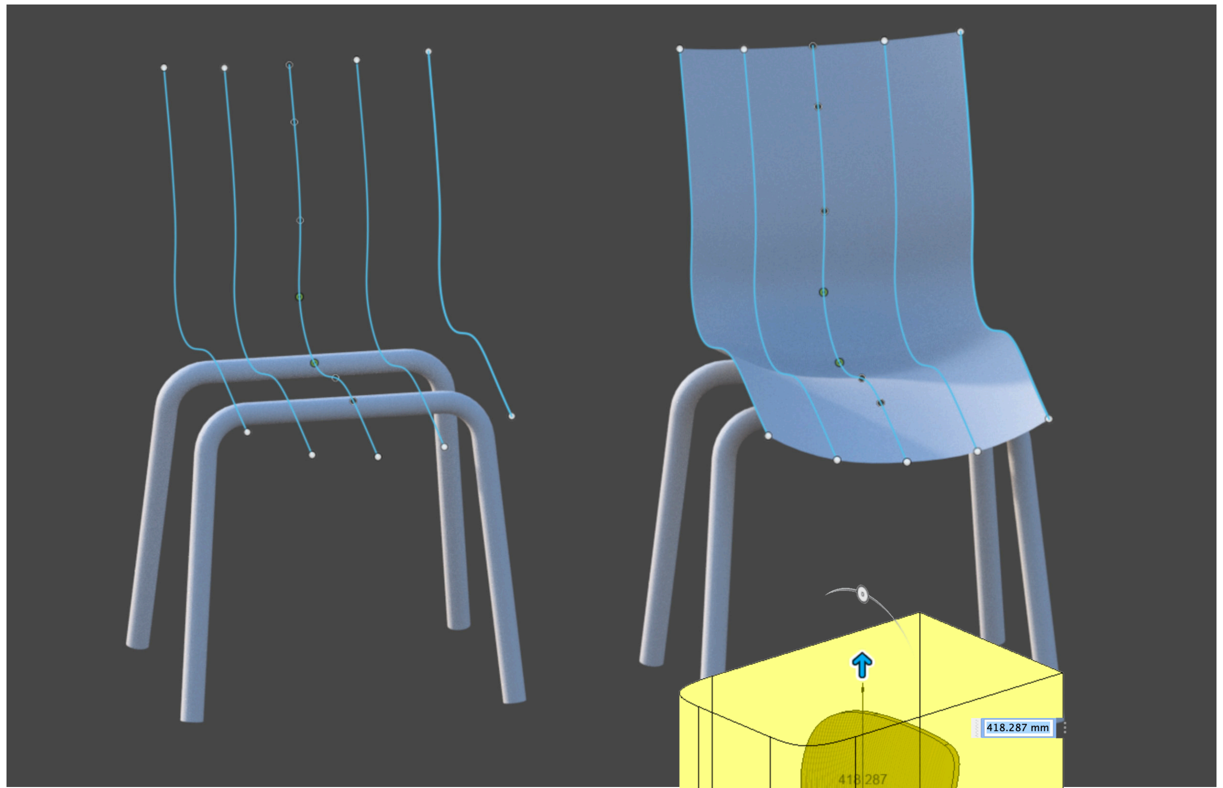

figure 68: visualizing the lofts

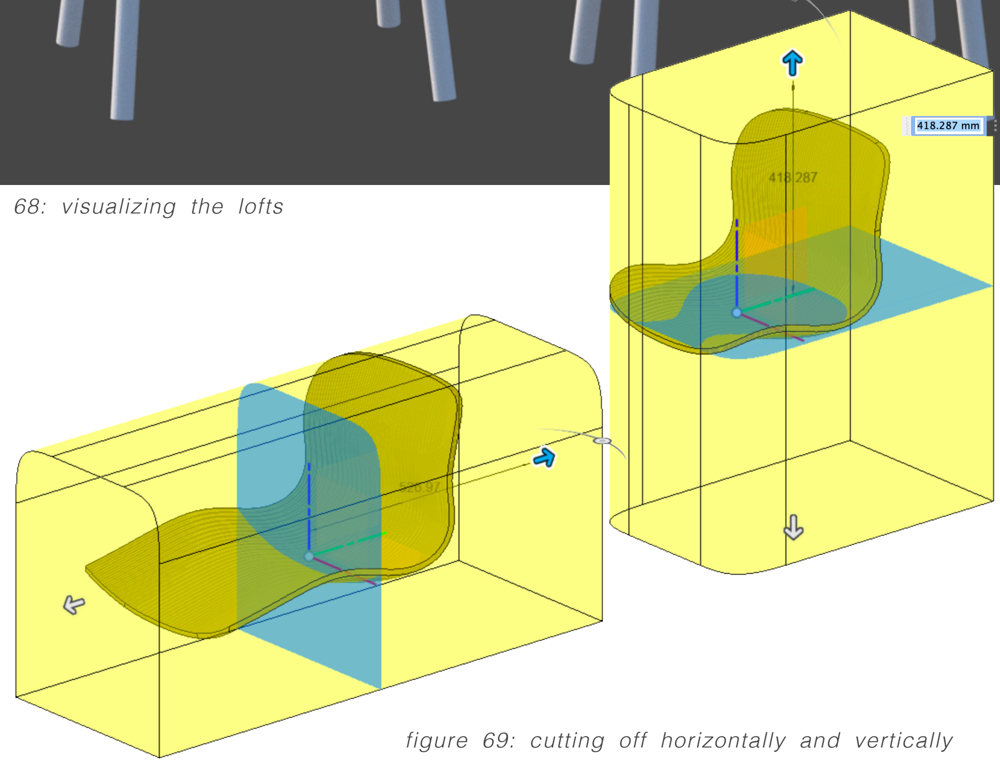

figure 69: cutting off horizontally and vertically

figure 71: closeup of the printed prototype

figure 70: various samples with varying layer heights.

6.4 Printing

For printing, the facilities of 3DRP were used. For the machine to recognize the model, it has to be modeled as a solid, see figure 72. With the use of the software Cura, this solid shape is transformed into commands (as a .gcode file) that the printer can execute. Cura also commands the printer to only print the outsides of the solid shape, as well as the preferred layer height, layer time, starting point, etc. As mentioned in section 5.1.7 and 5.4, after experimentation (figure 70), the resolution with a wall thickness of 10 mm, layer-height of 4 mm and layer time of 76 seconds were chosen. This was a coarser resolution than 3DRP had printed before but delivered a successful result, see figure 71, however some experimentation could still benefit the printability.

6.5 First layers and warping

The first layers are deposited upon a wooden print bed. These layers tend to lose their heat quickly and therefore shrink. The internal stress, especially in the corners, shrinks the layers and sometimes lifts the print of the print bed, which is undesirable for accuracy and can lead to failure of the print. To combat this phenomenon, the first layers are stapled to the wooden print bed and will stay at desirable dimensions. However, the first layers should be an additional margin that was later sawed off.

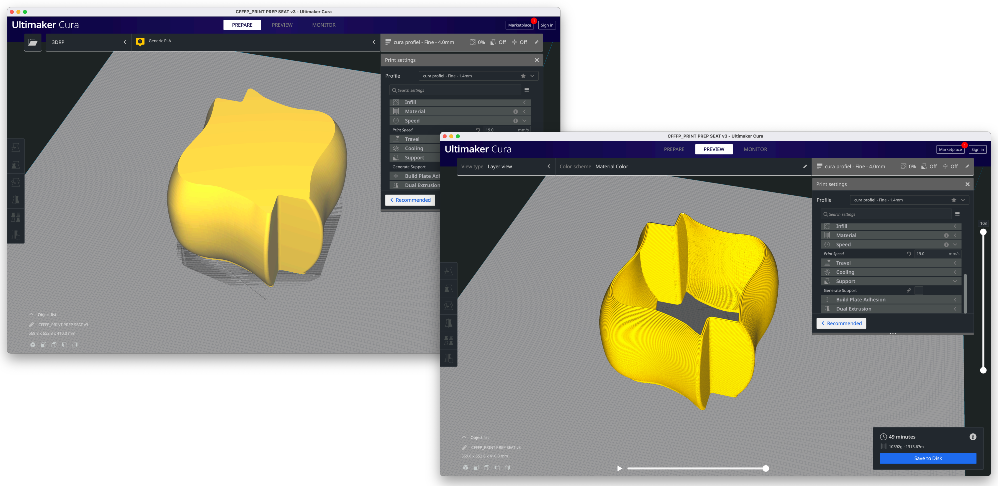

figure 72: cura converting solid bodies to a single loop.

figure 74: smoothing the welds to imitate a bent frame

figure 73: preparing for welding the bends

figure 75: the fit of the leg frame turned out to be too tight for the connection piece

6.6 Legs

Initially, it was planned to have the chair frame produced by an experienced steel constructor. However due to the lead times of four to six weeks, it was decided to mimic the desired result as closely as possible. The final chair-legs were produced by welding premanufactured welding elbows and straight tubes. This resulted in chair-legs with a mimicked bending radius of 45 mm, instead of the intended 60 mm. The process can be seen in figures 73 to 75.

6.7 Upholstery

The upholstery process (figures 76 & 77) was executed in upholstery studio Nest. Nearly everything was done by an completely inexperienced hand. The result is not perfect, but illustrates the possibility perfectly well.

6.8 Assembly

For this assembly process, the split-lines of the connection piece are placed underneath the chair legs to be out of sight. In the envisioned design, the rigid frame is assembled first, and inserted into the 3D printed connection piece

figure 77: the final upholstered seat

figure 76: manually upholstering

afterwards, as described in 5.5. For this to be possible the connection piece was expected to be more flexible, which caused some problems, see figure 75. In further iterations of the design, the insertion of the tube frame into the connection piece has to be improved. This could be done by adjusting the split line placement, or by finding a way of assembling the tube frame whilst being inserted in the 3D printed connection piece, instead of assembling the frame beforehand.

The finished prototype is displayed in figures 78 to 82, on the next page.

6.9 Final model presentation

figure 78:coopi viewed from above

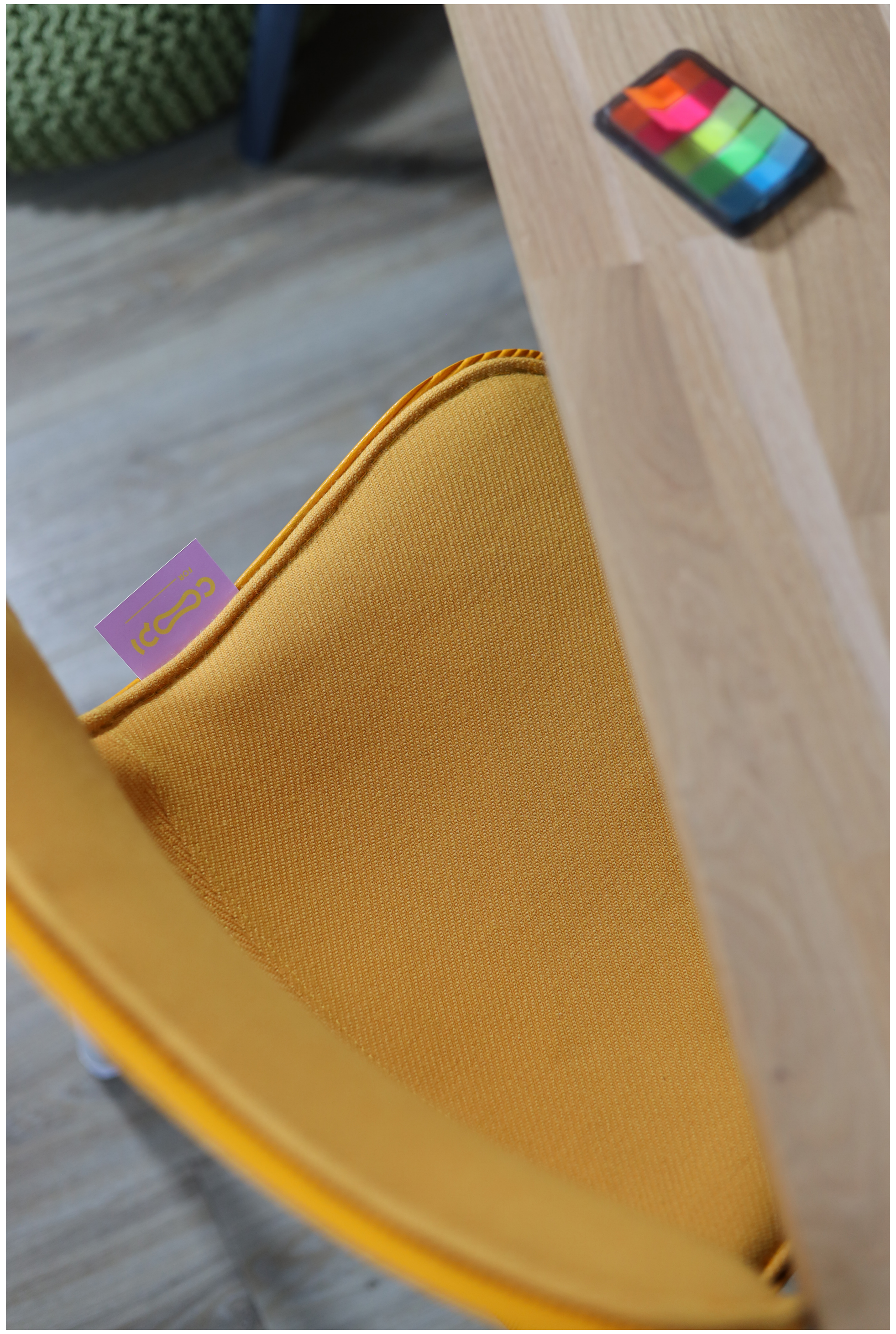

figure 79: three quarter view

figure 80: coopi in home working context

figure 82: close-up of upholstery

figure 81: details

coopi: 7. validation

7. Val- ida- tion

coopi: 7. validation

figure 83: painting process

7.1 Overall reflection on prototype

- The printing, separating and finishing turned out to be a lot easier and quicker than expected. The main issue that was encountered was the shrinkage of the material, as also described in section 6.5. Especially the connection piece, which exists out of two printed parts, was warped at first and had to be reheated and bent. Future iterations should compensate for this side-effect.
- The material is stiffer than expected, which caused some problems with the assembly. As described in 68. Future iterations should be improved.
- The upholstery process was also very doable. The result is not perfect, as it was not executed by a professional upholsterer. Worries about the material breaking when stapling, turned out to be unnecessary. One possible improvement would be a thinner, more flexible blind seam profile, as the used seam profile did not fully cover the staple.
- Visually, the product seems less balanced compared to the renders. Perhaps due to the fact that the legs have a different bending radius compared to the CAD model (see section 6.6). The prototype also seems smaller than imagined in the 3D workspace. Another reason could also be that the design was modeled while in isometric view mostly. It would be advised to iterate on the design to improve the real-life perception. Additional images on this topic can be seen in Appendix L.

7.2 Feasibility

Many choices have been based on the client being a start-up. Quick market introduction and keeping the concept simple and as executable as possible were important. Conscious choices were made to print with available technology, material and to avoid design ideas that involved longer research and development (such as printing cushioning, using meshes as upholstery, making the seat flexibility dependent on user weight, or introducing injection molds in the process).

The prototyping shows some room for improvement, but also proves feasibility. For the printing process of the prototype, the set up/experimentation process was limited, with more time the printing could be optimized with at least 20-25% (Noordhoek, 2022). Also the upholstery process was doable and can be executed more quickly and more neatly with some practice and experience (van Besten, 2022). Some changes may be necessary, but it can be concluded that the Coopi should relatively easily be developable and producible for the client.

7.3 Desirability

The desirability for this concept and this execution was tested with user interviews (n=4). Methods, notes and quotes are found in Appendix L. The perceived value, comfort, benefits and concerns of the concept were tested. According to the users, the experienced value of the concept balances quite equally between ergonomics, benefits for the living room scenario and the uniqueness of the design/manufacturing process. None of

coopi: 7. validation

these factors clearly outplays the other, but all are reasonably equally valued. Users were enthusiastic about a chair that offers ergonomy, convenience (for the home working scenario, compared to office chairs) and a compelling design and manufacturing process.

To give a better understanding the prior, the following quotes are grasped:

On ergonomics/comfort/sitting experience:
"It feels more supportive, very 'chill'. Normally my lower back hurts. I rate my pain a 6 or 7, now it feels like a 4 or 5. I don't directly have negative comments. It's really nice that it 'folds around your back', it gives a cozy feeling."

"The concept is valuable, if you have a correct posture; that's worth something."

"For home working and ergonomics, it's a strong concept, I don't see disadvantages."

"I think it would also stay comfortable [when sitting longer]. It is not really a chair that has pressure points, there are no points that will start to irritate."

On convenience:
"It is not a 'log' chair. It's beautiful to put in a room and doesn't take too much space, yet it feels ergonomically responsible."

"The biggest value is that it blends in your room instead of a big black chair. It can really become part of your interior, something that a big black desk chair couldn't. It is also a more friendly looking chair."

On the design and manufacturing process:
"Since it is a concept chair, it's something that people could value. People that are materialistic. Lawyers or marketing employees for example, they really like to have something to boast about, it's not a simple Ikea chair, that adds value to people."

"[...] you don't need to pick out of 50 colors. It's nice to have a pre-selected color. That is the vision of the designer, I'll make my house fit to it."

Common mentioned opportunities/ concerns for this concept:

- High quality branding: *"I don't think it belongs in the highest [price] range, it just doesn't have the name or reputation. If you would sell it [the concept] to Vitra, you could ask much more for it. Or Ahrend (to a lesser extent). Or the marketing campaign and branding should be really strong."*
- High quality packaging is expected.
- The company should be accessible. Since it is a personal product, personal customer service is expected.
- There is not that much added value in offering unlimited amounts of colors and color combinations.
- Sustainability seems of value as users made remarks on efficient packaging, repair, dis- and reassembly and local production. Circularity or using recycled material did not add much value to the asked users: *"I expect my body to stay the same. So I do see this as a sustainable purchase because I'd be sitting in it for years. Printing in recycled materials would be of added value, but it shouldn't cost more because of it. It would also be of added value if it would be locally produced, for example with social workplaces (sociale werkplaats)"*

Perceived monetary value:
After conversing with possible target users about the benefits and concerns of the concept, users were asked to compare Coopi to other chairs from various price ranges. All users placed the chair at a price point between €400,- and €700,-, but the majority mentioned a price tag between €600,- and €700,- With this in mind, it is quite reasonable to conclude that the concept as is, is perceived as desirable.

Suggestion:
This validation has been executed with a select number of participants. The prototype will serve as a good aid for continuing this research and gaining additional insights. Also the comments on ergonomics do not fully do justice, as the chair was modeled after only one person. It would be advised to evaluate ergonomics and comfort with specifically developed seats. In that case, the quality of finishing, painting, etc, would be of lesser importance.

7.4 Viability

Can the client make a sound business out of this? To answer this question, more information about the investments is needed. How are the user dimensions measured? Does this require development of an application and computing power? Is that also desirable to the consumer? And how much is needed for additional ergonomic research? Would the brand name and facilities of a partnership with a furniture company be of added value? Or would it help with investment costs? The client will be advised to critically evaluate these decisions before anything else.

8. Con-clu-sions

8.1 Concluding

Finally, this wraps up the reporting and the graduation project. It is wonderful to arrive at this point, with an end-result that beforehand was impossible to imagine. 3D printing technology offers fascinating opportunities. Yet, to develop a product that combines consumer, client, production, customization and styling, is another challenge in its own right.
Coopi is a new approach to producing customizable, scalable chairs. Utilizing the advantages of computer numeric production processes, combined with the advantages of manual ones. Coopi offers the benefits of a perfectly fitted office chair, in the form of a trendy, outspoken living room chair.

Through a diverse process in which simultaneously issues like print strategy, upholstering, stability and styling gradually developed. Many iterations resulted in a concept, of which one variant (based on the body of one person), was finally prototyped on 1:1 scale, and validated. This process proved the working, while also displaying room for improvements.

Overall, Coopi can be seen as an appropriate answer to the design challenge proposed by the client Zon&Hoofd, in which consumer, client, customization, production and styling come together.

8.2 Recommendations

As the concept for the Coopi was constructed, many answers and options were regarded. However, on some topics, the answers might not be adequate yet. Therefore recommendations towards the client, for a successful continuation are made.

- Carefully consider business validity. Especially when it comes to in-house printing and upholstering. Both can be executed cheaper and quicker when done in-house, but this comes with larger investment costs upfront.
- Rework and continue developing insights that were gained during the prototyping phase. The frame assembly should be improved and the blind seam profile did not deliver the imagined result. Also the stance of the chair should be stronger in real life and match the CAD.
- Consider the customer journey of the tailoring and purchase process. Is measuring through an (web-) application the desirable option? This is an intimate product and investment for the user.
- Ethically validate design decisions. How well does this design work for women or extremely short or tall users? The main design and prototype were based on the 3D scan data of just one person, who happened to be male.
- Styling vs accuracy: some design decisions were made to attain a visually pleasing result at the expense of the anthropometric accuracy. Did these decisions negatively impact comfort and posture, or do consumers prefer a visually pleasing design?
- Design packaging and the unboxing experience.
- Be bold. Also, this is a personal reflection (more in chapter 9), but perhaps, it is better to develop a strong concept that the company believes in. A statement, instead of a more concept that is always the middle way.

coopi: 9. reflections

9. Re-flec-tions

coopi: 9. reflections

9.1 Reflections

Hi, it's me! For the reflections we will be switching to a more informal writing style (the first person perspective), which I think is more fitting as we will be reflecting on my personal and professional growth during this project.

Chairs are emotional products. Every chair has a story and attracts a certain user. Especially in this context, a chair has to be a product that the user can identify with and relate to. But this does not only apply to the user who buys the product, but also for the person who designs it: *me*. At the beginning of the project, I was constantly searching for the right answers, the absolute objective truth: "How to make a chair that fits user group X, or scenario Y?" Though, later during the project, (and with the encouragement of my coaches), I started trusting more on my own intuition, and realizing that there is not one single objective best solution. Any student or professional designer would find a solution that will be a personal one. As the client selected me as a suitable executer of this project, they selected me based on trust in my intuition. My solution will be a different one than anyone would or could have done, but that is okay. That is even the beauty of it. Of course, the design still needs to be feasible, desirable and viable, objectively, but by giving my intuition more space, the process started speeding up in the second half of the project. Instead of keeping on searching for the most objective answers on screen and in my head (I have the tendency to do so), I started making more subjective decisions. This aided the development a lot. You learn a lot from proposing an option, trying it out and talking to the right people, oh, and it also became more enjoyable during this part of the process.

Related to this point, I learned to treat the opinions of clients and experts in different ways. A client knows what they want, what they can afford for example, but experts know what is achievable. Talking to experts helped speed up the process a lot. Especially when I started taking small 3D printed prototypes to upholstering studios, page 36 and 37. A lot of unforeseen opportunities (and difficulties) popped up. As I was not an expert on upholstering, tube bending or robotic 3D printing, I learned tons from talking to people who are. In the first half of the project, I gave a lot of weight to the opinions and ideas of my client, which was helpful for understanding their vision, but actually talking to experts sped up the process.

Related to the above, I wish I took a more material driven approach. Of course, the concept showcases the manufacturing processes by openly showing the 3D printed lines, showing the loop of the connection piece, which I think is visually quite strong. However I slightly underestimated the material. Only when prototyping the final model I learned about the internal stresses when separating the loops or about how stiff and strong this material actually is. Had I done earlier experimentation with the final material and manufacturing processes, it could have impacted the design decisions. However it still results in useful recommendations to the client.

During this design trajectory, I realized how product driven I am. I really love to zoom in the on the product itself, how it can be manufactured, or how it looks. In the beginning, I expected the client to also have a likewise focus. What I did not fully grasp was the overarching wish of the client. In the briefing of this graduation the client expressed the wish to create beautiful chairs that are ergonomic. However the way I see it now, is that the client also favored such business proposal: relative low investments and quick market introduction. This completely makes sense, but it took me a while to grasp this. Personally I see my product focus as my strength as a designer, but after this insight, I think there is another step to make when it comes to validating the viability of the design decisions I made when it comes to investments. For future projects I would seek closer collaboration with experts related businesses startup and investments.

Lastly: be careful when showing renders. I have an effective, quick yet sloppy modeling skill. Especially during the ideation phases, I can make something look convincing quickly. This helps to convey my work to the client, leading to enthusiasm and understanding of my ideas. However it can also be a pitfall: it creates the expectation that the design is final and can easily be sent to a manufacturer, while that's not true at all. For example the chair in figure 49 was in no way producible. During the 'sculpt' modeling, the dimensions were not accurate, multiple parts interfered with each other an there was poor line continuity. Before sending it to the manufacturer, I had to remodel the chair to be accurate, avoiding interference, etc, it needed to be built from scratch again: which took about seven to eight working days.

9.2 Acknowledgments

First of all, *Erik* and *Eliza*, thank you for your support, feedback, approachability and sometimes giving me a little push, it was a pleasure.
Leon and *Koen*, I always enjoyed sparring together during our weekly zoom calls, I really admire your approach positivity.
Jose from Studio Nest, coming to your upholstery studio were some of the most pleasurable days of this project. Thank you for introducing me to the profession, thank you for being so incredibly kind and helpful.
Mark thanks for your help with the logo, you took it to the next level.
Marije, your stunning interior made my project look better! Thank you so kindly.
PMB staff, you also deserve a kind word for all the help, advice, and coffee.

This report marks the end of an era. Not only is this the end of the graduation project, it also marks the end of my studies in Delft. Never have I regretted going to Delft, my only regret is not going there earlier. It has been a transformative journey with some of my highest highs and lowest lows, truthfully, a period that will forever be dear to me. Since joining the faculty of Industrial Design Engineering, I received the support of wonderful people. I would be happy to express my gratitude.

Dear *Peertje*, you really helped me get through it. Thank you for all the support you have given. I am incredibly grateful for having you here at the finish line.
JVB39, I was instantly accepted by you guys and you made my time living in Delft amazing.
M16hoven (tav included) Thank you for all the good times, distractions and your patience. You guys are always there for me. Thanks for all those times that I could borrow cameras, tools or your cars. It can never be too much for you guys. I will start cleaning up my personal spray booth (our balcony) as soon this is over.
Familie Hofenk-van Asma during the beginning of my masters, I experienced an unlimited amount of support and enthusiasm for me and my studies, thank you so much for this period.
Last but not least, everyone from *Je Suis Studio*. Meeting you was a blessing. It helped me enjoy my time graduating beyond what I could have expected.

coopi: 9. reflections

Bibliography

3D Robotprinting. (n.d.). 3D Robotprinting. Retrieved November 21, 2021, from https://www.3d-robotprinting.com/3d-printen

Alderson, S., Ball, R., Barber, E., Bogdan, E., Campbell, A., & Zappaterra, Y. (2013). Het Designboek. Uitgeverij Terra Lannoo bv.

BrandmadeTV. (2015, December 23). How a Herman Miller Aeron Chair is made - BrandmadeTV [Video]. YouTube. https://www.youtube.com/watch?v=fI8YcxOzkHI

Brüll, M, (2021): personal communication, June 2021

Cox, S. (2021): personal communication, Juli 2021

DINED. (n.d.). Dined Anthropometric Database, dutch adults 2004. Retrieved January 30, 2022, from https://dined.io.tudelft.nl/en

Doucleff, M. (2018, August 14). Can't Get Comfortable In Your Chair? Here's What You Can Do. Https://Www.Npr.Org. Retrieved November 21, 2021, from https://www.npr.org/sections/health-shots/2018/09/24/649169060/cant-get-comfortable-in-your-chair-heres-what-you-can-do?t=1620584286461

Fieldlab UPPS. (n.d.). Het Fieldlab. Retrieved November 21, 2021, from http://www.upps.nl/en/het-fieldlab-en/

Groenesteijn, L., Vink, P., de Looze, M., & Krause, F. (2009). Effects of differences in office chair controls, seat and backrest angle design in relation to tasks. Applied Ergonomics, 40(3), 362–370. https://doi.org/10.1016/j.apergo.2008.11.011

Han Kim, K., Young, K. S., & Rajulu, S. L. (2019). Neutral Body Posture in Spaceflight. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 63(1), 992–996. https://doi.org/10.1177/1071181319631129

Harrison, D. D., Sanghak, S., Croft, A. C., Harrison, D. E., & Troyanovich, S. J. (1999). Sitting Biomechanics Part I: Review of the Literature. Journal of Manipulative and Physiological Therapeutics, 22(9), 594–606.

Jamison, J. R., Harrison, D. D., Harrison, S. O., Croft, A. C., & Harrison, D. E. (2000). Sitting Biomechanics, Part II: Optimal Car Driver's Seat and Optimal Driver's Spinal Model. Journal of Manipulative and Physiological Therapeutics, 23(1), 37–47. https://doi.org/10.1067/mmt.2000.103476

Keegan, J. J. (1953). ALTERATIONS OF THE LUMBAR CURVE RELATED TO POSTURE AND SEATING. The Journal of Bone & Joint Surgery, 35(3), 589–603. https://doi.org/10.2106/00004623-195335030-00007

Mabtoul, F., Verhoeff, R., Reinders, M., & MacLean, D. (2018, January). Research into Additive Manufactured Plastic Components for Offshore.

Ministerie van Infrastructuur en Waterstaat. (2021, July 19). Onderzoek wijst uit: thuiswerken is een blijvertje. Nieuwsbericht | Rijksoverheid.nl. https://www.rijksoverheid.nl/actueel/nieuws/2021/07/14/onderzoek-wijst-uit-thuiswerken-is-een-blijvertje

Noordhoek, E.J.L., (2021): personal communication, Rotterdam, September 2021

Overheid.nl. (2020, August 1). Arbeidsomstandighedenregeling. wetten.overheid.nl. Retrieved November 21, 2021, from https://wetten.overheid.nl/BWBR0008587/2020-08-01%23Hoofdstuk5

Tempelman, E. (2021, June). NSFD: Cost price. Unpublished.

Toromanoff, A. (2016). Chairs by Architects (1st ed.). Thames & Hudson.

Victoria and Albert Museum. (2015, October 8). How Was it Made? The Panton Chair [Video]. YouTube. https://www.youtube.com/watch?v=xim1m2Bhvzc

van Besten, J., (2021): personal communication, Rotterdam, September 2021
van Besten, J., (2022): personal communication, Rotterdam, Januari 2022

Vink, P. (2004). Comfort and Design: Principles and Good Practice (1st ed.). CRC Press.

Zaan A.K., (2021): personal communication Rotterdam Haystore, September 2021

Image sources

Figure 5: https://www.designboom.com/design/mean-mawj-3d-printed-chair-01-22-2021/

Figure 6: https://facfox.com/docs/kb/how-3d-printing-direction-orientation-affects-strength

Figure 8: https://facfox.com/docs/kb/how-3d-printing-direction-orientation-affects-strength

Figure 11: http://www.positivehealth.com/article/back-care/the-vital-role-of-seating-in-back-care

Figure 21: https://www.de-splendeur.nl/winkels/studio-nest/

Figure 22: https://www.vitra.com/nl-nl/living/product/details/eames-plastic-armchair-daw

Figure 23: https://www.connox.nl/categorieen/meubilair/stoelen/hay-over-een-stoel-aac-22-met-voorbekleding.html

Figure 25: https://www.furnco.co.nz/BLIND-SEAM-PROFILE-p/plblind7mm-cl.htm

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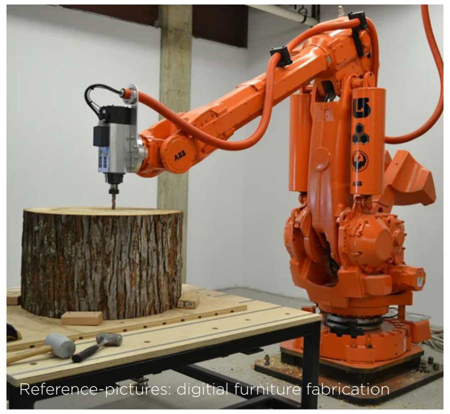
10. Ap- pen- dices


Reference-pictures: digital furniture fabrication

TAILOR-MADE DESK CHAIR

FROM DESIGN TO PRODUCTION

Graduation project IDE TU Delft
Master: integrated product design

17.02.21

MISSION
We want ergonomic desk chairs that make your heart jump, chairs that not only sit well but look amazing, without the wheels, levers and plastics. A tailor-made chair you don't want to hide in an office but deserves a place in the middle of your living room.

YOUR TASK
Your assignment is to design a desk chair of the future which is fully digitally manufacturable with an automated process, using 3D-printing and/or CNC milling in a file-to-factory process. You will focus on both the design and the technical aspect of the realization of the chair. You will for example research areas like structural soundness, and how to create comfort with these digital manufacturing processes. Prototyping and testing will be an important part of the process. The research results should give an overview of the advantages and disadvantages of the possible digital fabrication techniques for desk chair design. The results of your research, a prototype of a chair designed by you, is an important part of the development of a new desk chair we want to launch next year.

WHO ARE WE LOOKING FOR
A TU Delft IDE graduation student with an interest for ergonomics and digital fabrication.

WHAT DO WE OFFER
You will be working closely with us, but with a lot of freedom in the project. We have a great office in the city centre of Rotterdam. There will be a budget available for you to develop prototypes during your research.

> A University-student will receive an internship allowance of €250,- per month.

> Peter Vink is available as chair

CONTACT
Interested? Call us for more information (+316-19683557) or send your resume and a motivation letter to Leon Zondervan: leon@zonandhoofd.com

WHO ARE WE?
Zon&Hoofd is a young start-up with a mission to revolutionize (home)office furniture by combining high-end design with ergonomics, beautiful materials, digital fabrication techniques and cutting edge technology. We are young designers with a passion for innovation, adventure, and making great projects together.
It is founded by architects Koen Hoofd en Leon Zondervan from Zondervan Architectuur. A studio working on various architectural projects in Rotterdam and surroundings. The lack of design and radical innovation in office seating motivated us to expand from architecture to product design. Right now we are focusing on making the first prototypes, in preparation of developing them as commerical products.


The Zon&Hoofd / Zondervan Architectuur office


IDE Master Graduation Project Brief_van den Dikkenberg_Lean_...   Open with Adobe Acrobat Reader DC

Personal Project Brief - IDE Master Graduation   TU Delft

Tailor-made desk chair through digital manufacturing   project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 28 - 05 - 2021   03 - 12 - 2021 end date

INTRODUCTION **
Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The world has changed and working from home has become 'het nieuwe normaal'. This trend is predicted to be a keeper, even after the pandemic. McKinsey (2020), predicts an increase of 400 to 500% of hours worked from home compared to before the crisis, in western Europe. Next to that the Dutch people are sitting a lot of the time. On average 8.7 hours a day, but for the higher educated on workdays, 10.1 hours according to RIVM (2015). With these numbers, Dutch folks spend more time seated than any other European population.

To accommodate the human body while working sedentary, various ergonomic chairs exist. However, ergonomic chairs were not designed to be put in a home, but in the office environment. Take a look at the website of Ikea and you will immediately see the difference between dining chairs and chairs for the office environment. It does not take long to realize that chairs for home are much more stylish, while the chairs for the office environment look way more ergonomic and comfortable. When taking ergonomic chairs apart it becomes apparent that a chair consist out of dozens of parts (image1). All of these parts are required to offer one product that will fit 95% of the population, from the 5th percentile female to the 95th percentile male. For example, a Herman Miller Aeron can be be adjusted in more than 750.000 positions. This ensures that companies can create a one-size-fits-all solution which is ideal for offices, where chairs will be shared. On the other hand, these highly adjustable chairs are bulky ugly products, for instance, see (image2).

This illustrates the design opportunity for this project. People will be working from home more often than ever, but ergonomic chairs are more complicated products than we usually like to put in our homes. There is a gap between the simplistic, beautifully designed, minimal chair, and the chair that has many parts in order to be adjustable to the body of the consumer. Enter the company, Zon&Hoofd, who would like to bride this gap. By utilizing digital manufacturing techniques, such as 3D printing or CNC machining, a chair can be made in any size to optimally fit the bodily measurements (anthropometrics) of the consumer. By using digital manufacturing processes, Zon&Hoofd hopes to offer a chair that is optimally tailored to the consumer, while being more elegantly designed, for the home working context.

space available for images / figures on next page

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30   Page 3 of 7

Initials & Name L.J. van den Dikkenberg   Student number 4308662

Title of Project Tailor-made desk chair through digital manufacturing

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TU Delft

Personal Project Brief - IDE Master Graduation

introduction (continued): space for images

image / figure 1: Herman Miller Mirra Disassembled. (n.d.). https://mbdc.com/wp-content/uploads/MirraChair-disass

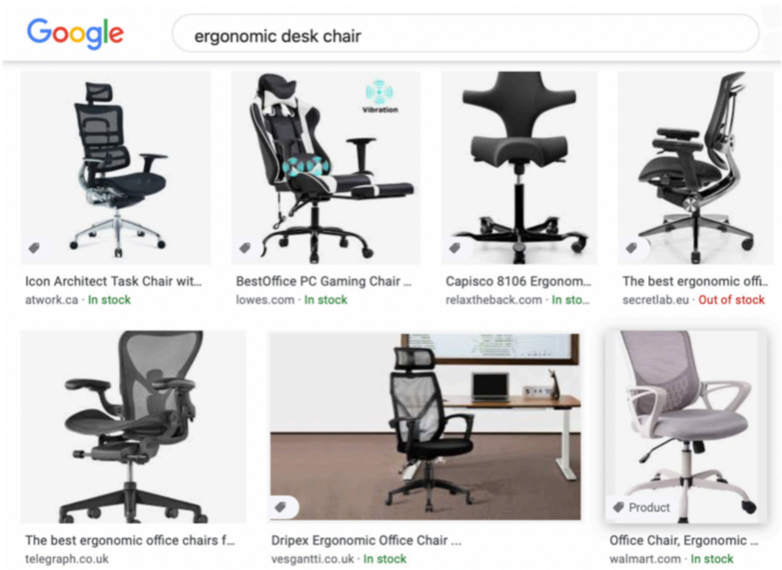

image / figure 2: What ergonomic chairs look like according to google https://www.google.com/

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TU Delft

Personal Project Brief - IDE Master Graduation

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Digital manufacturing can fill a unique position in the realm of desk chair manufacturing. The nature of digital manufacturing allows each product to have unique dimensions, enabling the opportunity to tailor chairs to the body of each individual consumer, so that a chair does not need adjustment mechanisms to fit well. By taking digital manufacturing of desk chairs as the basis of this graduation project, it challenges us to make a chair that is more ergonomic than typical dining chairs, while being more aesthetic and suitable to the home work scenario than ergonomic office chairs.

Within this project we are challenged to make these production processes an attractive opportunity for the client. Since digital manufacturing processes vary enormously in price, lead time and material property, it will be important to find and apply digital manufacturing in a manner that is valuable and reasonable for Zon & Hoofd.

On the other hand, we will be looking into what requirements a tailorable desk chair should meet for the home working scenario and how this scenario impacts the production methods. This includes aspects such as postural support, comfort, movement and aesthetics.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Use the advantages of digital manufacturing processes to design a desk chair that is tailorable to the dimension of each individual user. The chair should be attractive and optimized for the home working scenario.

We aim for a hands on, explorative process. The end result will be a design in the form of 3D model and a practical and/or visual prototype. Obviously supported by a well-considered and well-documented design process and recommendations in the form of a written report.

 appendix B: personal project brief

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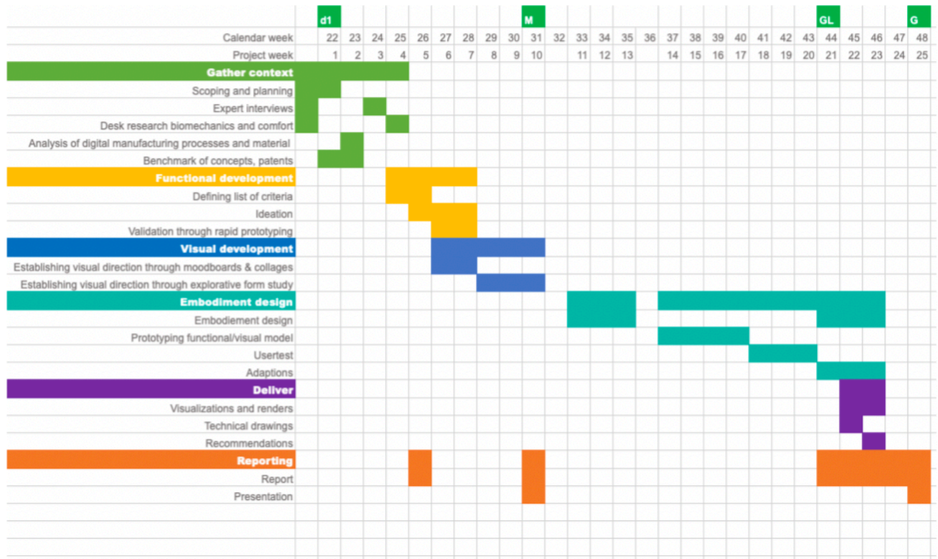
Personal Project Brief - IDE Master Graduation

TU Delft

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 28 - 5 - 2021 3 - 12 - 2021 end date



IDE Master Graduation Project Brief_van den Dikkenberg_Lean_... Open with Adobe Acrobat Reader DC

Personal Project Brief - IDE Master Graduation

TU Delft

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

My bachelor, Industrial Design at the University of Technology Eindhoven, was a way more interaction and user experienced version of the study. Upon coming to Delft, I knew what I wanted to learn; to provide value by designing and embodying physical products. After completing ACD, AED and the elective space, I am still driven by the embodiment aspect of the design process, to make the value tangible.

During the elective space I did a lot of visual projects, such as Zen Design, Memetic Design, Automotive 3D, Automotive Sketching and Computer Sketching. During this period I've become more excited about the challenge of turning a design from 2D to 3D and the memetic, lifestyle based approach of styling products, a challenge that's very prominent in this graduation opportunity. During these courses I also drew a lot of inspiration from the styling of chairs and the lifestyle of architects, which provides a clear link to this project.

As a personal goals for this project I have full intent to work as visually as possible. If the process permits, I would love to develop my Grashopper skills as well.

Sources

Bill Stumpf. (n.d.). Bill Stumpf. Retrieved May 21, 2021, from https://www.hermanmiller.com/en_mde/designers/stumpf/

The future of work in Europe. (2020, December 14). McKinsey & Company. https://www.mckinsey.com/featured-insights/future-of-work/the-future-of-work-in-europe#

Nederlanders zitten veel, jongeren het meest | RIVM. (2015). National Institute for Public Health and Environment (Rijksinstituut voor Volksgezondheid en Milieu (RIVM)). https://www.rivm.nl/nieuws/nederlanders-zitten-veel-jongeren-meest

Herman Miller Mirra Disassembled. (n.d.). https://mbdc.com/wp-content/uploads/MirraChair-disassembled-1.jpg

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

FIG. 8

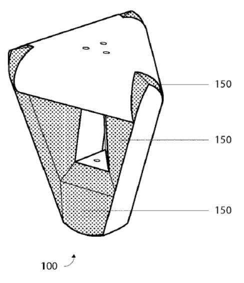
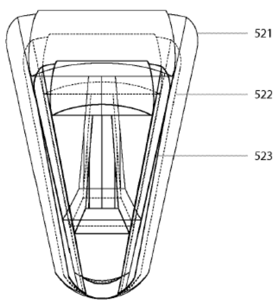


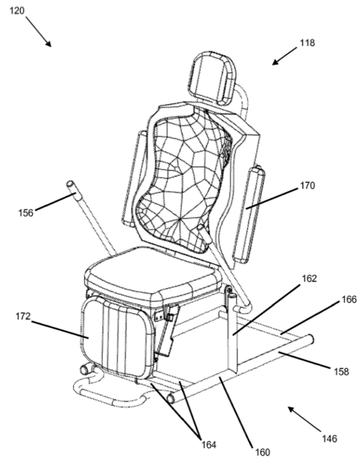
FIG. 26A

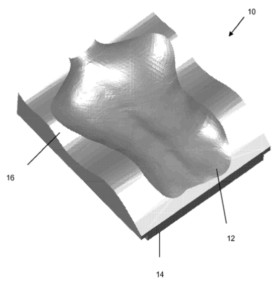


01

Ergonomic chair made from paper substrate with embedded sensor, computer readable medium for interacting with the chair, method of making the chair or other structures from paper substrate. Relevancy: Size of the stool is parametrically determined in accordance with the body of the user; including seat edge curvature, hip width, knee height, and thigh length. The stool is generated by Rhino and Grasshopper, and made with a paper substrate, which is digitally die cut. Acquiring the anthropometrics is not specified in the patent.

Patent status: **invalid** 2020-03-09
EP3245900A2
F.xhttps://www.anatomystandard.com/Columna_Vertebralis/Sagittal_Alignment.html





02

A method of producing a support article, a support article, and a support device incorporating the same.
Relevancy: the patent claim to *acquire a cloud of 3D points, generated by a non-contact 3D digitizer* (3D scanner), and *the support article* (backrest) *to be formed by CAD device, which is undefined.* Applications mentioned int the patent are "chair" and "wheelchair".

Patent status: **invalid** 2012-02-08
EP2116153A1

F.xhttps://www.anatomystandard.com/Columna_Vertebralis/Sagittal_Alignment.html

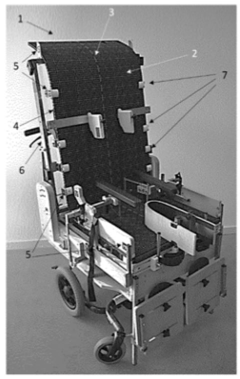


Fig. 1a

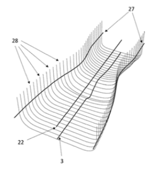


Fig. 3c

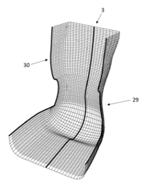


Fig. 3d

03

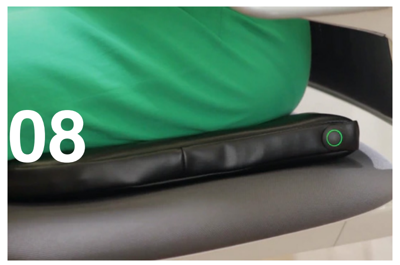
Method and element for determining the shape for a custom-made seat shell
Relevancy: Usually seat orthoses are made with vacuum bags with PS pellets. The patent claims a device that detects parameters of the user's body, which are digitally converted to a 3D model. The patent describes a product that measures antropometric data. Does not claim embodiment of the actual seat pan.

Patent status: **valid** 2018-08-15
EP3361400A1

F.xhttps://www.anatomystandard.com/Columna_Vertebralis/Sagittal_Alignment.html

Patents

market scan for inspiration



A quick analysis of current relevant products and concepts can promptly show what competition can harm the business proposal. While at the same be a source of inspiration.

01 Spinal orthosis
There are multiple companies offering a custom fit orthosis by 3D scanning the user, mesh-mixing a 3D model fitted to the scan data and finally printing the orthosis. Various companies deliver various orthesis, i.e. spinal orthosis, wrist braces or orthotic sole inlays. Apart from the customization, benefits include waterproofness, flexibility or material/weight reduction.

02 TiMbandAir is the result of 3D scanning a babyhead. The helmet is 3D printed and corrects skulls suffering from flat head syndrome or similar deformities.

03 Lumbar support can be improve the worst seat for only 20 dollars.
04 Custom seat orthoses are a specialized orthopedic intervention, for example used as wheelchairs. The user will sit in a bag filled with PS pellets, which is vacuumed to the body. The resulting shape is 3D scanned, mesh-mixed and CNC milled from foam and clothed. Roughly the same process is used to mold a F1 seat to the driver. A custom seat takes around 15 days to be produced.
05 A fascinating example; these UE headphones are moldable at home. A UV source in the headphones cures the material to the shape of the inner ear.
06 Along the same lines, Snugs makes custom earplugs. Whereas they used to professionally mold a plug directly to one's ear, Snugs Go let's the user scan their own ear with a smart-phone and calibration card. The algorithm matches the data of the scan to a database with closely comparable shapes. The final result is mailed at home.
07 Various products, such as the Lumo Lift are wearable devices which notice bad posture and nudge the user through haptic feedback.
08 The Darma or Sensi mat are examples of initiatives that sense user posture and provide feedback. Transportation companies as BMW and Lantal combine sensing with active pneumatic intervention.
09 The Generico chair is one of many 3D printed chair concepts. This example specialized in material and weight reduction while using the material stiffness to make the backrest flexible.
10 Lilian van Daal's central theme is biomimicry. By mimicing the shape of funges, van Daal transforms FDM printed material in a soft comfortable one, so the contact area of this chair is cushion-like. Her work has been adapted to bicycle and car seats too.
11 Perhaps the most inspiring example found is a tailored customizable wheelchair, the Layer GO. SLA printed, and adapted to the user's dimentions, while offering customization, for example, with different colors, or mesh shapes. The Layer Go is not for sale. Likely because of the high SLA costs for a large product like this.

appendix C: market scan for inspiration

DATA SET

Since there are numerous products in this category, we could analyze all of them, or, we take products from lists defined by influential blogs. The following data set gives an assumption of popular desk chairs from ranging price and functionality categories.

https://www.gearpatrol.com/home/a456035/best-office-chair/

http://www.home-designing.com/unique-stylish-ergonomic-home-office-desk-chairs-for-sale-online

https://www.gq-magazine.co.uk/lifestyle/gallery/best-office-chairs-ergonomic?image=606453f3e5932c50ea301022

https://www.standard.co.uk/shopping/esbest/home-garden/best-ergonomic-office-chairs-home-a4469786.html

Herman miller €1593

Alphason €87

Comhoma €104

John Lewis €150

John Lewis €291

Herman Miller €733

Humanscale €848

Teknik €110

Amazon Umi €188

Yaheetech €58

Herman miller €1314

Humanscale €673

Habitat €105

Modway €90

Varier Thatsit €657

HAG Capisco €845

Vitra Panton €300

Herman Miller Embody €1425

Ikea €320

Muuto Cover €409

Interstuhl gesture €1100

AAC24 €375

Herman Miller €579

Steelcase Series 1 €370

Eames Vitra €218

Kartell Spoon €577

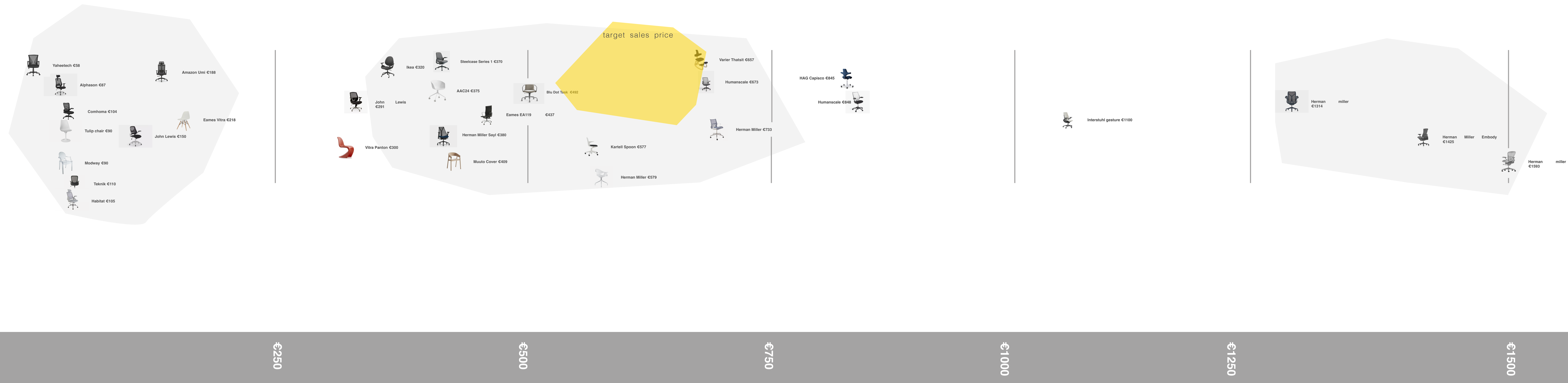
Herman Miller Sayl €380

Tulip chair €90

Eames EA119 €437

Blu Dot Task €492

appendix D: Competitor analysis



Price spectrum

Conclusion:
1. adjustabillity not clearly linked to high price. Cheap chairs can, too be perceived adjustable
2. Dining chairs are perceived less adjustable. Regardless of the price.

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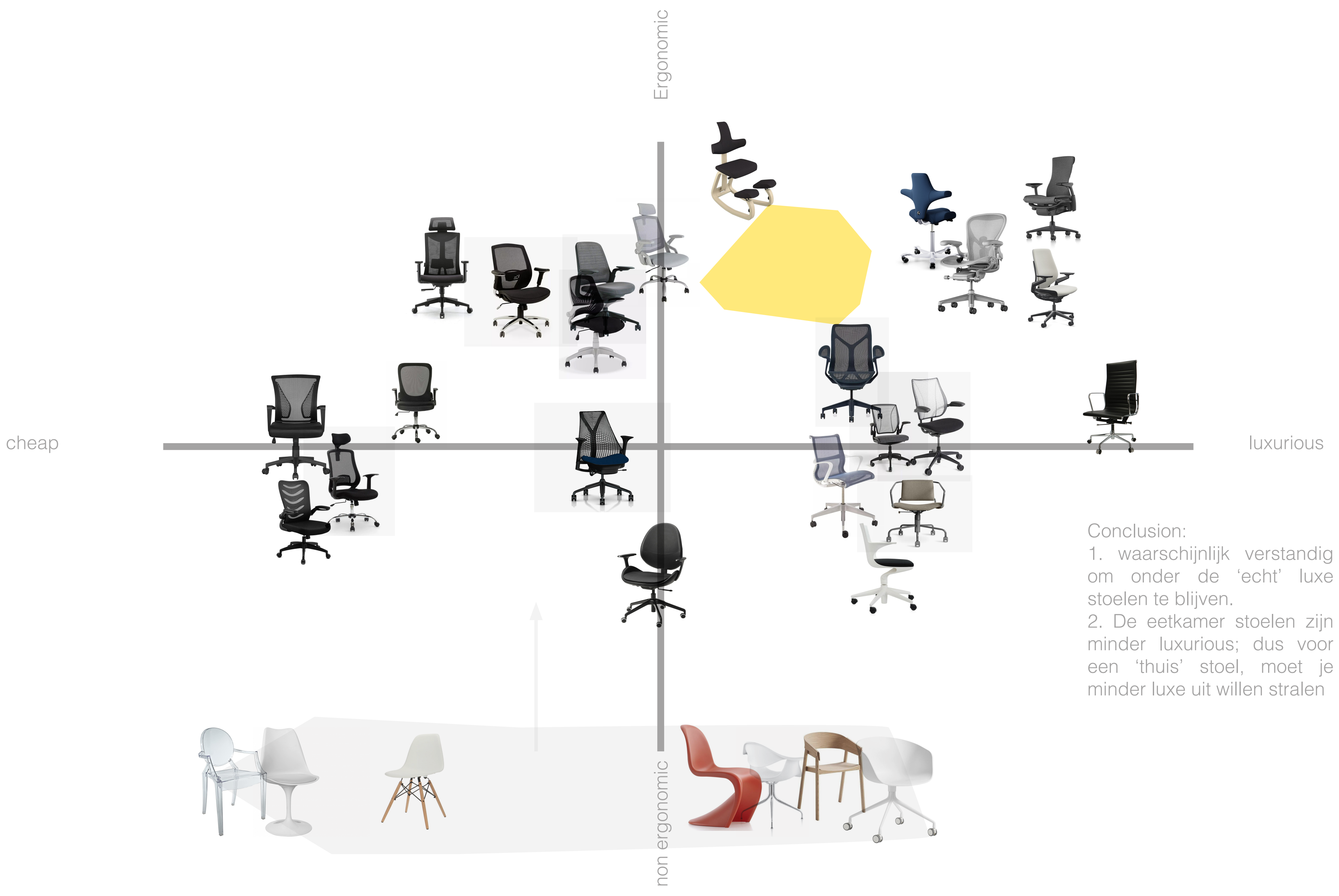
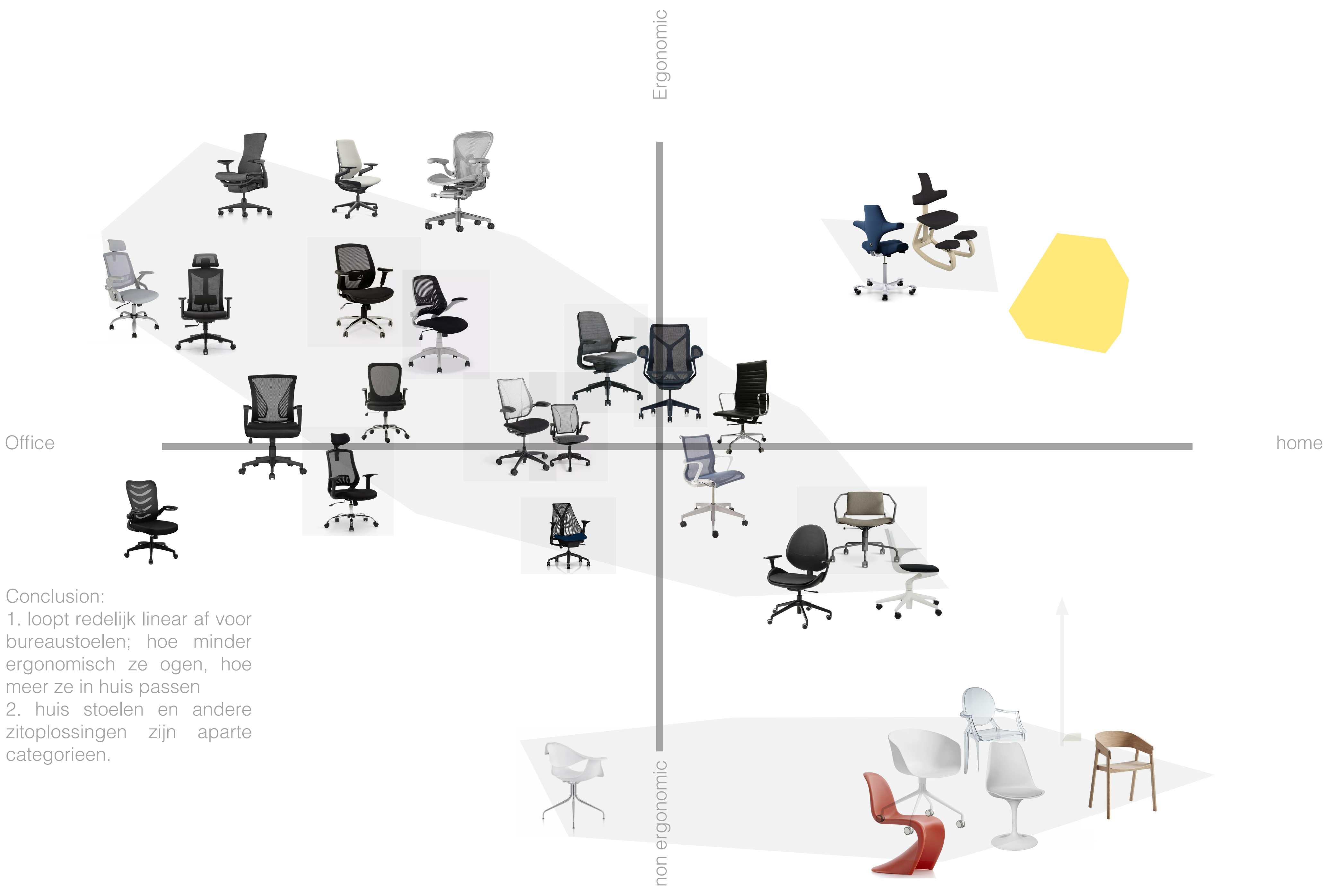


Conclusion:
1. waarschijnlijk verstandig om onder de 'echt' luxe stoelen te blijven.
2. De eetkamer stoelen zijn minder luxurious; dus voor een 'thuis' stoel, moet je minder luxe uit willen stralen

appendix D: Competitor analysis



Conclusion:
1. loopt redelijk linear af voor bureaustoelen; hoe minder ergonomisch ze ogen, hoe meer ze in huis passen
2. huis stoelen en andere zitoplossingen zijn aparte categorieen.

appendix D: Competitor analysis

Conclusion:
1. Prijs zegt niets over adjustability.
2. prijs zegt niets over home/ office perception
3. bureaustoelen zijn voornamelijk highly adjustable en diner stoelen zijn low adjustibility, maar meer home like
4. low adjustability will increase homey perception

Interview transcript Frank Tilman

'I will give you quite a scare' is what Frank Tilman said when I first called him to arrange an interview. With this, he referred to the amount of knowledge and his critical viewpoint about how humans should sit and how chairs help us to do so (or rather, do not help to do so). On the 14th of May, I visited Frank Tilman in his workplace De Zitacademie on the Noordereiland in Rotterdam, where we had a lengthy conversation over a cup of coffee, while he took me on a journey to try out different ways of sitting.
Frank has tons of relevant experience on the subject. Graduated as physiotherapist, thirty years ago, Frank started Tilman Ergonomie in which he spend years advising clients on ergonomic solutions such as standing desks or Stokke chairs. As opposed to only focusing on products as solutions; Frank was way more intrigued by the way humans use their body, the way our bodies tell us to sit. In 2009, Frank started De Zitacademie, with which he coached hundreds of clients. Instead of teaching them how to adjust a chair, he teaches how to find their optimal seating position, by finding the balance in their own body. Apart from that Frank has been involved in designing several chairs and seating solutions.

appendix E: expert interviews

pelvic balance

Together with me as interviewer, as well as with hundreds of clients (private and for companies), Frank lets you experience where to find the best balance in your body. "We have completely forgotten what sitting is, people think they have to sit completely straight, but that is not working." Frank says. "Instead, I am teaching them where [in their bodies] to find the balance". Frank demonstrated the main principle to me on a stool instead of a chair. "A stool forces you to find your own balance, while a chair invites you to slouch" he says, and this balance is coming from the pelvis. When you allow yourself to sit on your ischium tubercles (zitbeenknobbels), it allows you to rotate freely. "Your trunk and your head are resting on your pelvis. When your pelvis weakens [and sags back] your lower back has to compensate."

> "If you are sitting slouched, you don't have to lift up your trunk and head, you just need to rotate your pelvis!"

he explains.
According to Frank, this balance is something we have just forgotten about. But it is still available to us; "with De Zitacademie, I teach people in two and a half hours to understand how to find their pelvic balance, regardless of where they are sitting."

If there is something that agitates Tilman, it is the state of the industry when it comes to seating. From physiotherapist to office chair manufacturers, they don't seem to realise that a correct posture comes from internal balance, according to Tilman.**"Sitting up straight has become a dogma",** a goal which, without finding the pelvic balance, is unreachable and demotivating. "We are stuck with the notion that we have to sit straight up with angles of 90 degrees", which requires us to place our feet on the floor in front of us, with 90 degrees to the upper legs, etc. This is complete nonsense according to Tilman.
Accordingly, even ergonomic chairs invite us to slouch. The weight of our trunk leans against the backrest and will force you to slide down, which makes your pelvic tilt posteriorly, resulting in a stretched out lower back. The same goes for the seat pan, which according to Tilman, are often too long and too deep. This results in too much support. When you are carried by the seat pan, you cannot find your balance through your ischium tubercles (zitbeenknobbels).
Because of these misconceptions of seating, we've forgotten what sitting and what our pelvic balance ('intrinsic motion' as Tilman calls it) is. When asked if it's only a dogma, Tilman explicates a bit more; "the biggest challenge for designing chairs is that we're working with old habits." We think we know what we want in chairs, but we don't. At the same time marketing plays a huge role according to Tilman. Chairs have to be as beautiful as possible, which is at the expense of a proper mechanism. Tilman points at the RH Logic 3 as an example, a chair with a mechanism that allows the user to move freely, while staying in a good posture. The newer generations are made to be thinner, cheaper and more beautiful, at the expense of the mechanism. The Logic 3 has a very direct pivot point, which allows you to find your balance, also while moving around. "A chair like this, moves along with your body, while other chairs require you to shift your weight first, before the chair starts moving. This results in improper posture", Tilman says. "Only 5% of office chairs can do this", a direct result of the wrong priorities. The same goes for armrests for example, we think we need them to properly sit, yet you rarely see anyone use them. They are just a way for companies to make more money.

> "Chairs have to be as beautiful as possible, which often comes at the expense of a proper moving mechanism."

> "Comfortable chairs invite the user to sit with a lazy posture which prevents a healthy pelvic balance"

personality

Another interesting topic during this conversation was the nature of personality during sitting. Tilman says that each person has their own way of finding their balance. During his activities with De Zitacademie, he worked with 1600 clients. "Only 6% prefers to sit with an angle of 90 to 95 degrees (thigh-trunk angle), 36% prefers 95 to 110 degrees, and 58% chooses an angle between 110 and 135 degrees." This thigh-trunk angle is just one sitting property people have, everyone has their own preferences when it comes to other aspects such as seating height, feet placement, etc. The difference in posture comes from our variations in biomechanical properties. "One of the reasons people prefer the 90 to 95 degree angle is often overweight, these people have more mass in front of their pivot point, you won't find tall people in this category." Also, "often you find that males have less control on their pelvis compared to females."
Another aspect that influences posture is personality. "Some people just need to be more active while sitting to be able to pay attention. Or very shy people tend to slouch more."

> Tilman says that each person has their own way of finding their balance.

When asked what the adjustability does, in regards to these different personalities Tilman also replies firmly; "it just makes it worse. A chair may have five different ways of adjustment, that leads to loads of different setups." So, it becomes much harder to understand, if you look at the RH Logic 3, which has a superb moving mechanism; "what happens when people don't understand the chair... people lock the mechanism!". Tilman emphasizes; **it is not the chair that makes us sit well, it is understanding our pelvic balance.**

future

When asked about the future and the impact of the corona crisis on sitting, Tilman is quite optimistic. "Working from home creates extra awareness. All of a sudden people are responsible for how they sit, compared to al ergonomic facilities at the office." Also Tilman is very keen on younger generations, which he believes to be more critical towards the dogma's.

interview transcript bureaustoelwijzer

19 May, 09.28 Jeroen Koppenaal, at Bureaustoelwijzer

Lean: [00:00:04] Volgens de arbo wetgeving moet je volgens mij het de rugleuning naar achter kunnen schuiven?

Jeroen: [00:00:24] Dit is een ander principe. Nou is het nooit de bedoeling van herman miller geweest om van deze stoel een arbo technisch hoogstaand verhaal van te maken. Om de doodeenvoudige reden dat dat niet gaat, want er is te weinig verstelbaar. Ja dus op npr normering en dat soort zaken, dat gaat gewoon niet met deze stoel. Hij is daar ook niet voor.

Lean: [00:00:48] Die betekent betekend dat dat een werkgever deze stoel niet eigenlijk aan z'n personeel mag voorschotelen?

Jeroen: [00:00:56] Dat hangt er een beetje van af waar die voor gebruikt gaat worden. Ehm nou deze stoel [herman miller Cosm] hebben ze echt gemaakt om mensen die even kortstondig aan komen waaien en gaan werken om die een oplossing te bieden. Ja, en dan ook een oplossing omdat die door meerdere mensen gebruikt wordt. Moet het een oplossing zijn die niet een hele behandeling nodig heeft om in te stellen? Want mensen doen dat gewoon niet. Dus dit is echt een stoel en je komt even een uurtje of twee zitten. Je doet je ding en je gaat weer weg.

Lean: [00:01:27] En dan komt iemand anders.

Jeroen: [00:01:29] Ja dan komt iemand anders en die gebruikt de stoel ook weer. En dan is dit materiaal dan ook nog wat hygiënischer dan dan gestoffeerde stoelen dus. Daar is deze stoel echt echt voor gemaakt. En hij wordt heel veel door thuiswerkers of omdat mensen zo mooi vinden.

Lean: [00:02:03] Wat ik wel interessant aan vind is dat je zegt van mensen willen dan deze stoel voor thuis werken. Zie je dat bij andere stoelen ook terug? Of is dat echt per se deze?

Jeroen: [00:02:16] [Wijst naar de Aeron] De meest iconische ter wereld. Ja, dat is de Aeron. Dit is de ja die wordt gezien als dé stoel.

Lean: [00:02:25] Wat is er aan deze stoel dat mensen hem graag willen?

Jeroen: [00:02:28] Nou euh, dat heeft echt te maken met uhm, dat ergonomie en vormgeving hier goed samenkomen. Een mooie ergonomische stoel bestaat bijna niet. En dit wordt gezien als een als een mooie ergonomische stoel. Hij is niet euh, NPR genormeerd ofzo. Want dat dat de die gewoon niet moet. Herman miller bij dat bij de Aeron opgelost door drie verschillende maten te maken. Dus ze hebben buiten deze ook nog een maatje kleiner. En ze hebben m nog een maatje groter. Euh ja, die staat bijvoorbeeld hier. Dat is een enorme stoel.

Lean: [00:03:13] Ja. Dus worden de mensen die langer zijn en breder zijn?

Jeroen: [00:03:19] Ja, die stoel die groeit dan ook in alle richtingen. Het is wel, qua zit diepte, de hoogte en breedte. Voor thuis zie je dat mensen gewoon naar andere dingen kijken. Het mag wel kantoor achtig zijn, maar dan wel op een mooie manier. [laat voorbeelden zien]

Lean: [00:04:15] Wat voor mensen komen voor een actieve stoel?

appendix E: expert interviews

Jeroen: [00:04:18] Nee, daar komen ze niet per se meteen voor. Dat is meer waar ik ze naartoe leidt. Kijk zitten is niet goed. Dit is een Capisco. (Dit ontwerp is al 30 jaar oud). Het zitten op een Capisco is gewoon niet ongezond omdat je open zit. Dus je knieholte in een hoek van meer dan 90 graden, waardoor je automatisch tussen je bovenbenen en je romp ook een hoek van meer dan 90 graden krijgt. Ja, daarmee kantelt je bekken eigenlijk naar voren en is de druk op je op je onderste wervelschijven wordt daadwerkelijk minder.

Lean: [00:05:27] Is het een betere manier dan zitten dan op een instelbare stoel?

Jeroen: [00:05:33] Ja, maar het grote probleem waarom mensen eigenlijk altijd last hebben van van lage rugpijn, dat is omdat zodra je in een hoek van negentig graden gaat zitten, dat is eigenlijk achterhaald; de open zithoek betekent meer dan 90 graden hier [bekken-rug] en meer dan 90 graden hier [knieeen]. Het is ook beter voor je doorbloeding natuurlijk, met name beter voor je bekkenstand.

Lean: [00:06:00] Ja, omdat je bekken dan meer naar voren kantelt?

Jeroen: [00:06:02] Je bekken is het startpunt voor je ruggenwervel, dus als dat bekken naar voren kantelt, dan kantelt je ruggenwervel eigenlijk mee en vertrekt veel mooier naar boven en plaats vol schuin naar boven. Als dat gebeurt, dan moet je onderin een correctie aan toe gaan toepassen en dan kan die onderste wervelschijven echt onder druk te staan.

Lean: [00:06:22] Ja, wat is er nog het belang van het dynamische zitten?

Jeroen: [00:06:30] De de houding is actiever sowieso. Dus het is gewoon meer bewegen. De ontwerper van deze Capisco, Peter Opzwik, die heeft ook altijd gezegd. En de beste werkhouding is eigenlijk de volgende. Met andere woorden, wissel maar af en en blijf maar bezig. En als je dat combineert met een zit-sta tafel ga je echt fluitend de dag door.

Lean: [00:07:05] Kost dat niet meer energie om op zo'n manier omdat je minder kunt leunen? [op een stoel als de Capisco?]

Jeroen: [00:07:12] Nou ga maar zitten. Ik denk dat je verbaasd zal zijn over de support die hier ervaart.

Lean: [00:07:40] Ja, nee, dat zit prima.

Jeroen: [00:07:42] Ja, zeker!

Lean: [00:07:49] Wat voor soort mensen komt voor zo'n stoel?

Jeroen: [00:07:54] Er komen ook wel mensen gericht voor deze stoel ja. Maar er zijn ook heel veel mensen die willen gewoon een goede oplossing. Dus die komen niet voor deze stoel. Die lezen overal dat de [Herman Miller] Aeron de beste stoel ter wereld is. Dat is die gewoon niet maar, het is wel een hele goede oplossing als je design en ergonomie samen wil laten komen. Dat zie je niet zo vaak gebeuren. Maar qua zitten is het... ja het is oke.... Die netstoffering in de zitting, dat is een een van de dingen die die die zij heel goed toepassen. Het ademt natuurlijk en netstoffering verdeelt de druk ook heel mooi. En er zit een voorwaartse neig in, dus die stoel beweegt ietsjes verder door naar voren. Waardoor je iets hoger kunt zitten en ook een klein beetje die open zithoek kunt creëren. Want omdat hij door naar naar voren beweegt krijg je niet het gevaar dat je je achterzijde van de bovenbenen afknelt omdat die naar voren beweegt. Dat Drugpunt dat verdwijnt eigenlijk daarmee? Ja, en daarmee kun je dan ook ietsje meer 'open' zitten. Niet veel, maar wel iets waardoor die toch net wat beter is dan een gemiddelde stoel in dat opzicht.

Lean: [00:09:14] Ja verkoop je je stoelen vooral voor particulieren of ook voor bedrijven?

Jeroen: [00:09:19] In eerste instantie was het voor covid vooral voor bedrijven. Ja, en nu hebben we denk ik hier in vijftien maanden tijd misschien wel 600 particulieren in de showroom gehad.

Lean: [00:09:29] Wat is het verschil wat zij voor voor thuis zoeken?

Jeroen: [00:09:37] Nou ja, kijk wat zij voor thuis zoeken is een oplossing die niet meteen het kantoor in huis brengt, dus dat het een soort veredelde kantooromgeving wordt. Ja, maar ze willen wel een goede oplossing. Ja, dat is een wat toch wel wat andere benadering. Bij bedrijven zeggen ze: kijk doe maar gewoon een NPR1813 en dan is het goed. Dat is helemaal niet zo. Want dat zegt alleen maar iets over de instelbaarheid van een stoel. Maar het zegt niks over het comfort zegt niets over de manier van bewegen. Het zegt eigenlijk helemaal niks.

Lean: [00:10:13] Dus je kunt eigenlijk beter zitten op op een niet gekeurde stoel?

Jeroen: [00:10:17] Ja ik ken een hele hoop niet NPR gekeurde stoelen die een stuk beter zijn dan wel NPR genormeerde stoelen, dus het zegt mij niet zo veel.

Lean: [00:10:27] Hoe lang zit je al het vak trouwens?

Jeroen: [00:10:30] Meer dan 20 jaar!

Lean: [00:10:30] Wat heb je in die tijd zien veranderen?

Jeroen: [00:10:33] Nou euh, dat mensen meer aandacht besteden aan welzijn op werkplek. Kijk, ik heb ik. Ik durf te beweren dat ik echt een van de allereerste in Nederland was die is begonnen met de verkoop van zit-sta bureaus. Dat had te maken met dat ik in die tijd een Deense vriendin had en ik was vaak in Denemarken. Ik zag daar dat in alle kantoren stonden daar gewoon zit-sta oplossingen. En dan heb ik het over ruim twintig jaar geleden. En ik vond het opvallend dat het in Nederland helemaal niet zo was. Terwijl ik wel vrij snel kon bedenken wat het voordeel was van een zit-sta oplossing. Dus ik ben toen naar de grootste Deense zit-sta fabrikant gegaan en ik heb ze gevraagd of ik het in Nederland en België het mocht gaan verkopen als exclusieve, zeg maar als importeur. Ja, dat vond ze prima, En ja, en dat euh, dat was echt pionieren in het begin. Ja, maar op een gegeven moment toch wel wat succes.

Lean: [00:11:50] Maar hoe groot is dat marktaandeel [van zit-sta oplossingen] nu?

Jeroen: [00:11:54] Het is feitelijk nu de norm. Bij elke aanbesteding van bedrijven of overheidsinstellingen of wat dan ook is, euh, een zit-sta bureau echter de norm.

Lean: [00:12:10] En voor thuis?

Jeroen: [00:12:11] Dat dat ook steeds meer. Maar dat komt ook door de prijzen. Maar laten we zeggen dat je in een fatsoenlijk zit-sta bureau. Nou ja voor 600 euro heb je inclusief btw gewoon een fatsoenlijke zit-sta bureau tegenwoordig.

Lean: [00:12:39] Ja, maar is wel exclusief zitten oplossing?

Jeroen: [00:12:42] Ja precies. Je moet wel rekenen dat als je gewoon een goede werkplek. Euh, echt een serieuze werkplek ben je wel tussen de 1000 en 1500 euro kwijt. Ja maar goed, aan de andere kant, ik zeg altijd mensen doen heel ingewikkeld, over beide vaak. Acht uur slapen enzo. Terwijl ik denk nou ja, reken maar uit hoeveel tijd je daar [je werkplek] doorbrengt. Dat zal misschien iets minder zijn, maar niet heel veel minder.

Lean: [00:13:12] Ja, wat is de de grootste mis conceptie die mensen hebben op het moment dat ze komen vragen om een stoel of een kruk?

Jeroen: [00:13:20] Nou, ik vind dat echt een van de grootste misconcepties is dat mensen vaak denken dat bijvoorbeeld een balanskruk een oplossing is om de hele dag op te zitten. Dat is het niet. Als je de hele dag ergens op wil zitten, dan heb je een rugleuning nodig. Omdat ook al is je houding goed, op het moment dat je moe wordt zak je toch in. En het het enige punt waar je echt ondersteuning in je rug nodig hebt is de holte van je onderdruk. Daar moet echt iets zitten, want die holte blijft opvullen.

Lean: [00:13:59] Ja, verschilt het nog per persoon hoe dat opgevuld wordt? Is één stoel voor mij persoonlijk beter dan voor jou?

Jeroen: [00:14:09] Ja maar dat heeft meer te maken met het gevoel van comfort dat een stoel je geeft. Daarom staan hier ook zo onwijs veel verschillende stoelen. Omdat ieder mens ervaart zitten uiteindelijk anders. Daar kun je geen pijl op trekken.

Lean: [00:14:31] Ok, wat zoeken mensen in comfort?

Jeroen: [00:14:34] Dat hangt heel erg van af. Meestal gaat het om het gevoel van ondersteuning en dan helemaal terwijl je beweegt dat die ondersteuning eigenlijk gewoon hetzelfde blijft. En dat is heel moeilijk, want het is vaak zo dat als naar achteren beweegt, dan kan het zijn dat je het contact met je onderrug en de rugleuning kwijtraakt.

Lean: [00:15:04] Waarom als je naar achteren leunt?

Jeroen: [00:15:06] Afhankelijk van de vorm van de stoel hangt het er vanaf waarmee je duwt [wijst naar onderrug].Dat is één van de sterke punten van de Aeron, Die kun je in elke positie blijven voelen. De [Herman Miller] Cosm geeft zelf tegendruk. Daar zit een mechaniek in, dat meet hoe zwaar je bent en welke tegendruk voor jou goed zou zijn. Het is een wat minder actieve stoel, dus het is een euh, het is een wat meer een comfort stoel. Hij heeft bijvoorbeeld geen voorwaartse zit neig. Maar goed, nogmaals, die Cosm wordt op hele andere gronden verkocht. Het zit euh, waarschijnlijk sowieso beter dan de beste stoel die Ikea aanbiedt. Dus ja, weet je uiteindelijk is het natuurlijk gewoon wel een goeie stoel. Ja maar weet je, ik ben wel een beetje beroeps gereformeerd, dus in mijn optiek zou dat nooit een advies zijn van van mij om te zeggen van nou die Cosm die raadt ik je aan om de hele dag in te gaan zitten. Weet je, mensen vinden hem mooi en mensen kopen ook op emotie. Ja, dus in dat opzicht ja...

Lean: [00:16:40] Daar ben ik wel heel erg benieuwd naar, wat voor type mens kiest meer voor uiterlijk? Wat voor type mens kiest meer voor comfort? Wat voor type mens kiest meer voor ergonomie?

Jeroen: [00:16:50] Mensen zijn gevoelig voor design. De Cosm die hier staat, die heeft ook nog een variant met een lagere rug, dus die vind ik zelf eigenlijk nog mooier qua vormgeving. Ik had bijvoorbeeld laatst een jong stel, hij was designer, die kwamen echt voor de Cosm. Het probleem was dat hij wel zei goh, ik vind hem wel goed zitten, maar hij vond uiteindelijk die Aeron beter zitten. Ja, dat was best lastig. Ja en prijs is natuurlijk ook nog een issue, vergis je niet. Hoewel mensen die hier komen vaak al wel weten dat stoelen te duur zijn omdat ze op onze site al hebben gezien wat de prijs van een ergonomische stoel ongeveer is natuurlijk. Ja, dus in dat opzicht ja. Zijn ze wel al een klein beetje voorbereid.

Lean: [00:18:19] Hoe merk je ook aan mensen als ze toch voor een goedkopere oplossing willen gaan?

Jeroen: [00:18:21] Ja, maar mensen die ooit voor een Ikea zijn gegaan, die komen vaak uiteindelijk hier op het moment dat ze op meer geld te besteden hebben. Een bureaustoel is in die zin wel een eerlijk product. Hoe meer geld je over het algemeen betaalt, hoe beter. En euh. En mensen komen hier ook uit nieuwsgierigheid, merk ik. Die zien wel de prijs van een Aeron. Ze lezen verhalen over hoe fantastisch die is. Ze komen vaak ook omdat ze wel benieuwd zijn hoeveel beter dat is dan hun Ikea stoel.

Lean: [00:19:13] En waar komen ze het meeste achter op dat moment?

Jeroen: [00:19:16] Dat inderdaad zo [beter] is. Het is natuurlijk echt razend knap als je een zitting kan creëren bijvoorbeeld, waar zoveel comfort in zit en ook in blijft zitten. Want er zijn ook heel veel stoelen met een net-gestoffeerde zitting. Ja, als je daar maar lang op zit zit je in een soort schepnet. Dus ja, dan is al het comfort eruit.

Lean: [00:20:55] Ja precies. Wat is belang van de verstelbare armleuningen?

Jeroen: [00:21:02] Een stukje ondersteuning. In Scandinavië vinden ze dat iets minder interessant. Wat wel belangrijk is, is als je een armleuning hebt, is dat die redelijk dicht bij je romp staat, zodat je niet met je ellebogen naar buiten moet gaan zitten. Een ander belangrijk iets is uiteraard de hoogte. Omdat je euh, als je je schouders ontspant hier een hoek van negentig graden moet maken. En last but not least, ze moet eigenlijk ook naar voren naar achteren kunnen schuiven omdat je met je buik tegen de rand van je bureau aan moet kunnen zitten. En als je armleuning voorbij je buik zit, steekt en niet, dan ontstaat er te veel ruimte. Want die armleuning is het verlengstuk van je bureaublad. Zo moet je dat zien. Als je een afgetraind lijf hebt, dan wil je wel met je buik tegen de rand van je bureau aan kunnen zitten. Als die armleuning niet naar voren en achteren kan en hij steekt te ver voorbij je buik, dan kun je dus niet goed aansluiten.

Lean: [00:22:19] Dus het is eigenlijk om de stoel op je lichaam aan te passen?

Jeroen: [00:22:23] Precies. De stoel wordt ingesteld naar jouw lichaamsdimensies zeg ik altijd. Ja en de hoogte van je werkblad volgt. En de hoogte van je werkblad is gelijk aan de hoogte van je armleuning.

Lean: [00:22:35] Zijn er bepaalde dingen aan de stoel die je, nadat hij is ingesteld op je lichaam, daarna nog wil kunnen variëren? Heeft het nog effect om tijdens de dag bijvoorbeeld de armleuningen te veranderen of de hoogte van de stoel te veranderen?

Jeroen: [00:23:00] Nee, de enige verandering die je zou moeten eigenlijk zou moeten doen is dat je af en toe gaat staan. Dus dat je een zit-sta tafel hebt waarbij je zeg maar drie keer per dag gewoon even een half uurtje staand werken verricht. Daarmee zou je jezelf de grootste dienst bewijzen. Ja, maar je stoel moet je laten zoals ie is.

Lean: [00:23:22] Dat denk je ook een probleem van Corona dat mensen nu echt meer thuis zitten en eigenlijk nog meer, behoefte hebben aan dat af en toe staan en lopen naar een koffie plek.

Jeroen: [00:23:32] Nou ja, mensen hebben in ieder geval behoefte aan een aan een goeie oplossing ook thuis. Dat is met name van belang ja, want tot nu toe zijn er echt heel veel mensen geweest die die rit dachten uit te zitten aan de eettafel. Wat we nu zien, met name de laatste drie maanden is toch wel heel veel mensen met met fysieke klachten. Tuurlijk helpen wij ook mensen die last hebben van, of net terugkomen na een hernia operatie, of beginnende lage rugklachten. Maar met name de thuiswerkers die nog geen oplossing hadden voorzien. Dat zijn echt wel de mensen die op dit moment echt met met de klachten beginnen te kampen. Ja, en die zijn natuurlijk eigenlijk te laat op het moment dat je actie onderneemt als je klachten hebt. Ik bedoel dan. Dan ben je eigenlijk te laat. Een goede stoel moet klachten voorkomen.Ja, soort van de bewustwording is te laat gekomen.

Lean: [00:24:51] Komt dat door het ontbreken van de lendensteun?

Jeroen: [00:24:55] Ja natuurlijk, in een eetkamerstoel kun je gewoon goed zitten. Nee. Er zit geen beweging in. Nee, ze is gewoon een statisch, t is vaste hoek tussen zitten en zittingen en rug.

Lean: [00:25:10] In hoeverre pas je je advies aan op het werk dat iemand doet?

Jeroen: [00:25:14] Dat is zeker van belang. Het zijn twee dingen: de tijdsduur dat je echt in de monitor zit te kijken. Dat is één en twee is ook nog hoe geconcentreerd je wilt kunnen werken. Bij sommige mensen, die zijn niet echt actief, maar niet kijken meer. Die zoeken vaak een bureaustoel die iets minder beweegt en iets minder afleidt vanuit die beweging omdat ze geconcentreerder willen kunnen werken. Dus. Ja, dat is heel erg verschillend, maar wat ook gewoon verschillend is, is de mensen zelf. Zo'n Capisco bijvoorbeeld wordt door sommige mensen ervaren als een geschenk uit de hemel. Ze kenden het niet, maar fantastisch. Ja en andere mensen kijken een beetje wantrouwend naar en denken aan het is wel heel exotisch. Het is een vrij complex verhaal dat uiteindelijk leidt tot 1 of 2 echt oplossingen die die iemand echt als zijn of haar oplossingen ervaart.

Lean: [00:26:35] Precies, dus als ik een stoel ga ontwerpen ga ik niet een stoel voor iedereen kunnen ontwerpen?

Jeroen: [00:26:42] Nee, nee, het enige wat je zou kunnen doen is dat je de stoel ontwerpt en dat die qua instelbaarheid wel zou voldoen. Laten we zeggen vanuit ja instelbaarheid zou voldoen voor heel veel mensen. En dan moet je binnen die NPR normeringen. Want vergis je niet, in de praktijk instelbaarheid is 1. Ja, maar de beweging is 2. Maar ook de vorm van een zitting en een kussen en ook een rugleuning is echt super belangrijk. En dan ook nog eens een keer de aansluiting tussen een zitting en je rug. Kijk, een stoel moet je bijvoorbeeld ook bij voorkeur op je plek houden. Dat betekent dat een stoel als je gaat zitten niet het eerste wat je doet is dat je dit doet [Jeroen zakt onderuit]. Een stoel die je goed op je plek houdt. Ja, is in mijn optiek al echt gelijk veel beter.

Lean: [00:28:05] Ja, wat ik wel interessant vind, want je had het over ook weer ook het. Het zit ook en en hoe dat aansluit. Als je bijvoorbeeld kijkt naar verschillende stoelen, de stoel daar achter. Die heeft echt zo'n vorm. Of die deze heeft meer een soort van golf erin.... [wijst naar verschillende vormen zitoppervlak]

Jeroen: [00:28:41] Dit is dan een allemansvriend [wijst naar een stoel]. Dat is de dikwijls niet te gepronontceerd. Maar de rugleuning kan 10 centimeter verschuiven.

Lean: [00:28:50] Ok, maar wat is het effect van de vorm daarvan?

Jeroen: [00:28:54] De vorm bepaald mede hoe goed jij blijft zitten waar je zit. Ga maar eens op deze stoel zitten, de Mirra van Herman Miller. Ga jij maar eens proberen naar voren te schuiven dat gaat bijna niet.

Lean: [00:29:10] Verschilt dat nog per persoon?

Jeroen: [00:29:13] Ja hoor, al is de aansluiting bijnegentig procent van alle mensen bij die stoel [Herman miller Mirra] echt heel goed is. Maar die stoel vind ik weer minder omdat de armleuningen te ver uit elkaar zijn.

Lean: [00:29:25] Maar waarom gebruiken ander Herman Miller stoelen dan niet zo'n zelfde vorm, als die vorm zo goed is?

Jeroen: [00:29:31] Ja omdat elke Herman Miller stoel from scratch wordt ontworpen en elke keer met een ander uitgangspunt.

Lean: [00:29:38] Elke heeft z'n unieke voor en nadelen? Ok, interessant? Hoe denk je dat de toekomst eruit gaat zien als het gaat om zitten en om stoelen?

Jeroen: [00:29:51] Uhm, nou, ik denk dat er met name ook veel meer stoelen gaan komen, zoals de Cosm: makkelijk instelbaar, snel instelbaar, omdat ik denk dat de kantoorfunctie in de toekomst echt gaat veranderen. Ik denk dat kantoren veel meer een hub functie krijgen waarin mensen samenkomen om te ontmoeten. brainstorm sessies hebben met elkaar. Waar je inderdaad dan aan kan komen waaien om even te werken. Wij worden door Herman Miller daarin best we gevoed met alle kennis. En je ziet nu al wel dat dat de dat dat nu wel gebeurt. Dat ook de grote bedrijven op die manier straks gaan werken. Minder centrale kantoren, meer regionaal. Kleinere kantoren, maar veel meer. Ja, om met collega's overlegd te hebben. Ja hebben dat overleg. Uhm, via een beeldscherm minder doet en in processen dan als je zo bij elkaar zit. Dus de dynamiek is veel beter als je met elkaar in één ruimte zit dan samen thuis achter je beeldscherm. Vriendelijker, huiselijker en groener.

Lean: [00:31:26] Hoe zou je dat in een kernwoord omschrijven?

Jeroen: [00:31:26] Ja een stoel moet snel op een goede manier ingesteld kunnen worden. Daar zit echt de kluts. Bij veel stoelen duurt dat te lang.

Melissa Brüll 10 may 2021
Of ergonomiespecialist.nl

Introduction
When designing products, one has to deal with the laws and safety regulations. For chairs that's no different. In fact, we've all heard about the 'Arbowetgeving' or 'arbeidsomstandighedenwetgeving' which apart from being a great hangman word, translates to 'working conditions legislation'. But what does that mean for this project? When is a chair approved and what happens when a (digitally manufactured) chair does not meet the right demands? From the 29th of April I interviewed ms. Brüll through e-mail contact. Brüll is advisor on ergonomics and occupational therapist. The conversation is transcribed below.

Main findings
-The Arbowet is very vague, it requires the employer to arrange a health working situation.
-There are more defined guidelines, but they have no legal base.
-The employer is by law required to offer products that follow the Arbowet, however it does not require the employer to sit in them. If the employer wishes to sit on a stool (or stand) that should be fine.
-The corona pandemic happened too quickly to adjust well. Expected is that the employer will need to provide resources for the home working situation in the near future as well.

Transcription

[Lean]What happens when the chair does not comply to the Arbowetgeving?

[Brüll] The employer is obliged by the Arbowetgeving to protect employees against unsafe or unhealthy work situations. That is the employer's duty. The law literally states that the employer is obliged to take care of the safety and health of employees with regard to all aspects related to work and to this end, the employer is obliged to pursue a policy that is aimed at the best possible working conditions.

On the one hand, this concerns the execution of the work, but certainly also the arrangement of the workplace. It is therefore important that the arrangement of the workplaces meet the safety and health requirements set by the law. Whatever is possible to adjust must be implemented. What is not possible should be adjusted as much as possible. The risks and consequences of workplaces that cannot fully comply with the Working Conditions standards must be reported in the RI&E.
The actual arbowetgeving can be read here: https://wetten.overheid.nl/BWBR0010346/2020-01-01#Hoofdstuk2

Because this Arbowet remains fairly vague, the Arbonormen and Arboregelingen have been formed. On the basis of these Arboregelingen, it can be tested whether the requirement set in the Arbowet is being met. Below is a quote from the Arboregelingen, chapter 5, article 5.1. This provides more clarity. For example, it states the following about desks and office chairs:

- the desk or work surface should allow for a comfortable posture for the user and has a low-reflection surface. The desk or working surface is sufficiently large and allows a flexible arrangement of screen, keyboard, documents and accessories;
- the work chair is stable, has a height-adjustable seat and a backrest, the height and angle of which are adjustable and gives the user freedom of movement and a comfortable working posture;

The Arboregeling can be read here: https://wetten.overheid.nl/BWBR0008587/2020-08-01#Hoofdstuk5

This still is not very specific, so there have been introduced standards regarding office chairs and desks. For office chairs the NEN 1335 and NPR 1813 and for desks the NEN 527. However, these standards are guidelines and not laws that office chairs/desks must comply with. These standards mainly provide information about the necessary dimensions and setting options to make the resources suitable for the majority of Dutch/Europeans. There are office chairs that meet these standards that you cannot sit on healthily. There are also office chairs that do not 1 on 1 meet these standards that you can sit on perfectly. What we [as ergonomists] find important in office chairs is:
-Encourages the office chair to sit upright
-What type of movement mechanism does the office chair have
-How does the chair let you sit; in a 90 degree position or with a larger seat angle

These are factors that determine whether a chair allows an ergonomic sitting position.

[Lean] Alright so there are a couple of predefined requirements, but who takes the responsibility if they are not met? What are the (financial) consequences?

[Brüll] If an employer does not comply with this, sanctions can follow. Which sanctions are imposed? I think it is better to submit these questions to someone who deals with a law degree on these matters.

[Lean] Okay, but I've seen a lot of stools in offices, they do not have adjustable backrests, which are required by the Arbowet. Does this means your employer cannot offer you an ergonomic chair?

[Brüll] So 'arbogekeurd' (health and safety approved) is a term that is often used, but doesn't actually exist. A stool indeed does not have a backrest so can never comply to the Arbowet.

[Lean] So what does that mean?

[Brüll] By law, the employer is only required to ensure your safety and health. When employers rely on the NEN1335 or NPR1813, this has no legal basis. If the arrangement and your physical health allows for a stool instead of a chair, this is no problem. Nowhere in the law it says that you have to sit (in a chair). When you are sitting in a chair, they are just guidelines.

[Lean] Crystal clear, so what about the corona working from home situation?

[Brüll] Since everyone suddenly had to work from home with Covid-19, employers turned a blind eye. However, someone is only allowed to work from home if the workplace at home is in order. At some point, I think the policy will also become stricter, given that working from home is becoming increasingly structural in nature. The employer also has a duty of care in the home situation and must provide the necessary resources. You can read more information about this here: https://thuiswerkplek.org/arbowet-thuiswerkplek/

appendix F: formability and comfort of foams

3D scan data

3D data of male figure
Edited in Blender
Scaled 1:5
Turned into a bucket seat
Beware of 3D scandata: contains pleats and creases of clothing

6mm

Polyether foam
Relative thickness of 30 mm
Takes on the shape of the 3D printed shell nicely
Small creases in extreme curvature parts such as the legs

8mm

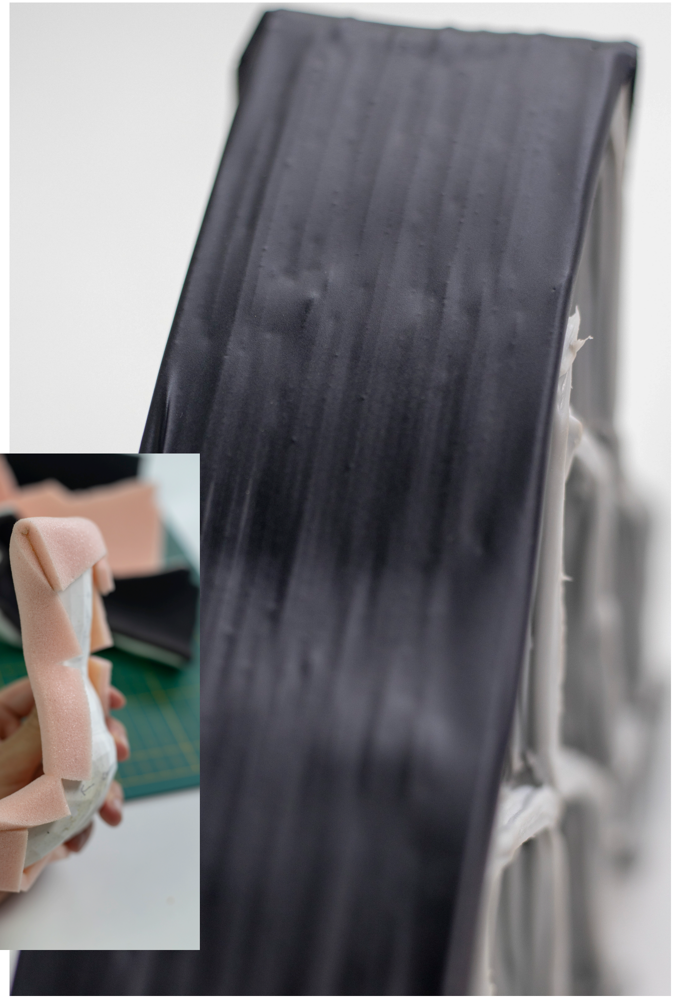
Polyether foam
Relative thickness of 40 mm
Takes on the shape quite nicely,
Also some small creases occur

10mm

Polyether foam
Relative thickness of 50 mm
Thick creases
Unable to stick to the back

6mm, layered

Polyether foam
Relative thickness of 30 mm in the middle, 50mm on the edges
Gives a smoother surface
Edges are folded around the plastic seat, but this becomes too thick, like a lounge chair. The folded material needs extra nicks



Vinyl wrapped 3D print

Vinyl does not do a good job op covering up the layers of a coarsely printed (1.2 mm) object
Imperfections clearly visible

type	thickness	hardness [1]	comfort	flexibility
Polyurethane HR 45	20mm	Soft	Adheres well to the exact body imprint. Sits comfortably. Less comfortable when the imprint was slightly off.	Extremely formable
Polyurethane HR 43	30mm	Medium	Feels softer than the prior (while being harder), but hard to detect big differences. Sits comfortably.	
Polyether SG 40	30mm	Hard	Most comfortable option. Hard to detect differences with HR 43, 2mm and HR 45 3mm, but more comfortable in the lower back.	Still formable
Polyether SG 40	35mm	Hard	Feels a lot harder, as a more active option. The back feels to stiff.	More difficult
HR 43 3mm in the back SG 40 3mm in the seat	30 & 30 mm	Medium & Hard	Mixed opinions, hard to notice a difference between one slab of foam, but the test subject preferred a single piece as it gives more support.	Extremely formable
HR 45 2mm in the back SG 40 3.5mm in the seat	20 & 35 mm	Soft & Hard	More comfortable than either material on its own.[2]	Extremely formable
HR 45 2mm in the back SG 40 3mm in the seat	20 & 30 mm	Soft & Hard	Very comparable to the previous option.	Extremely formable

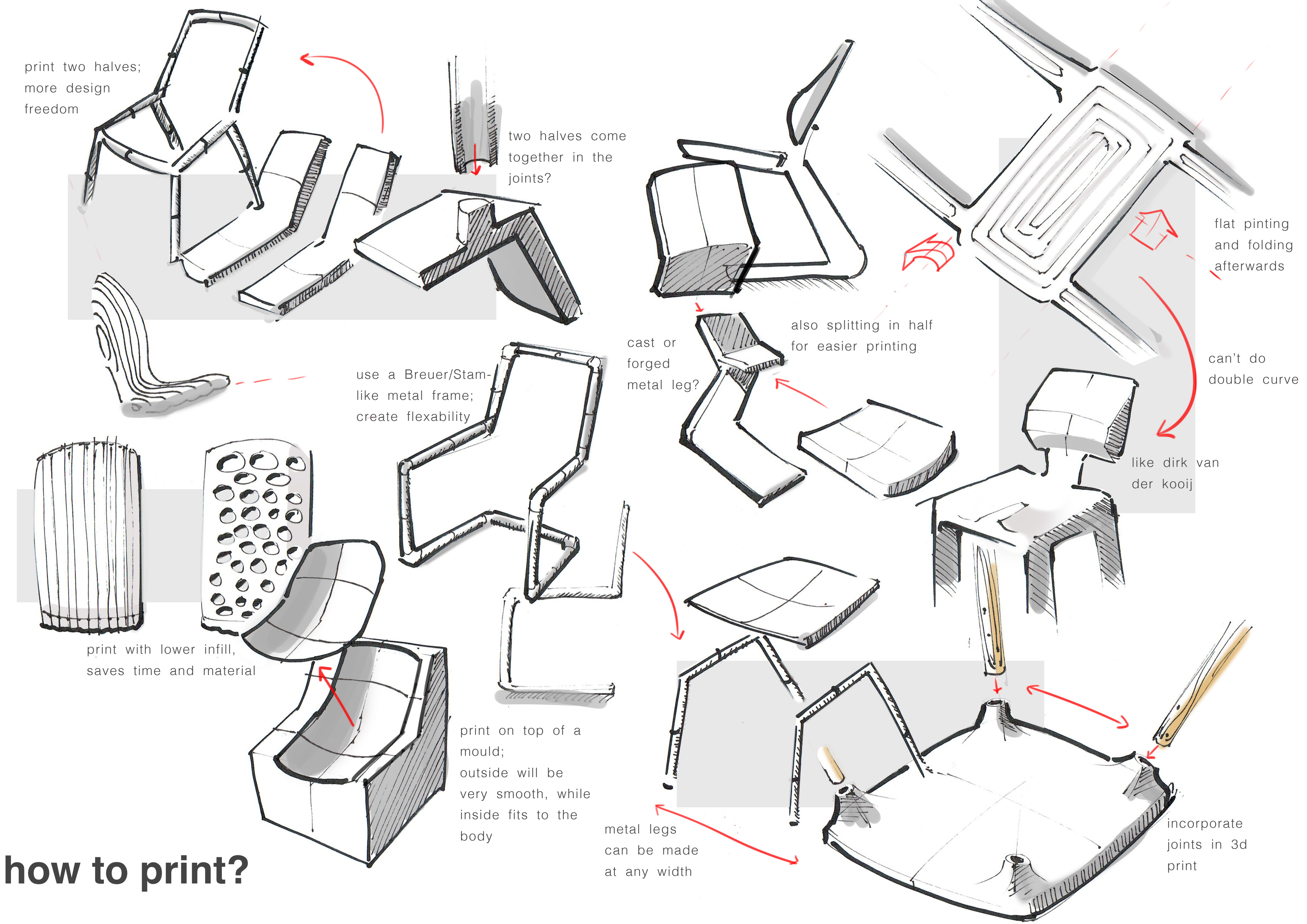
1. hardness is a marketing term, not measured or not proportionate with HR and SG values
2. in contrast to the previous option, the combination was preferred over a single slab of 2mm HR 45 of 3.5MM SG40

appendix F: formability and comfort of foams

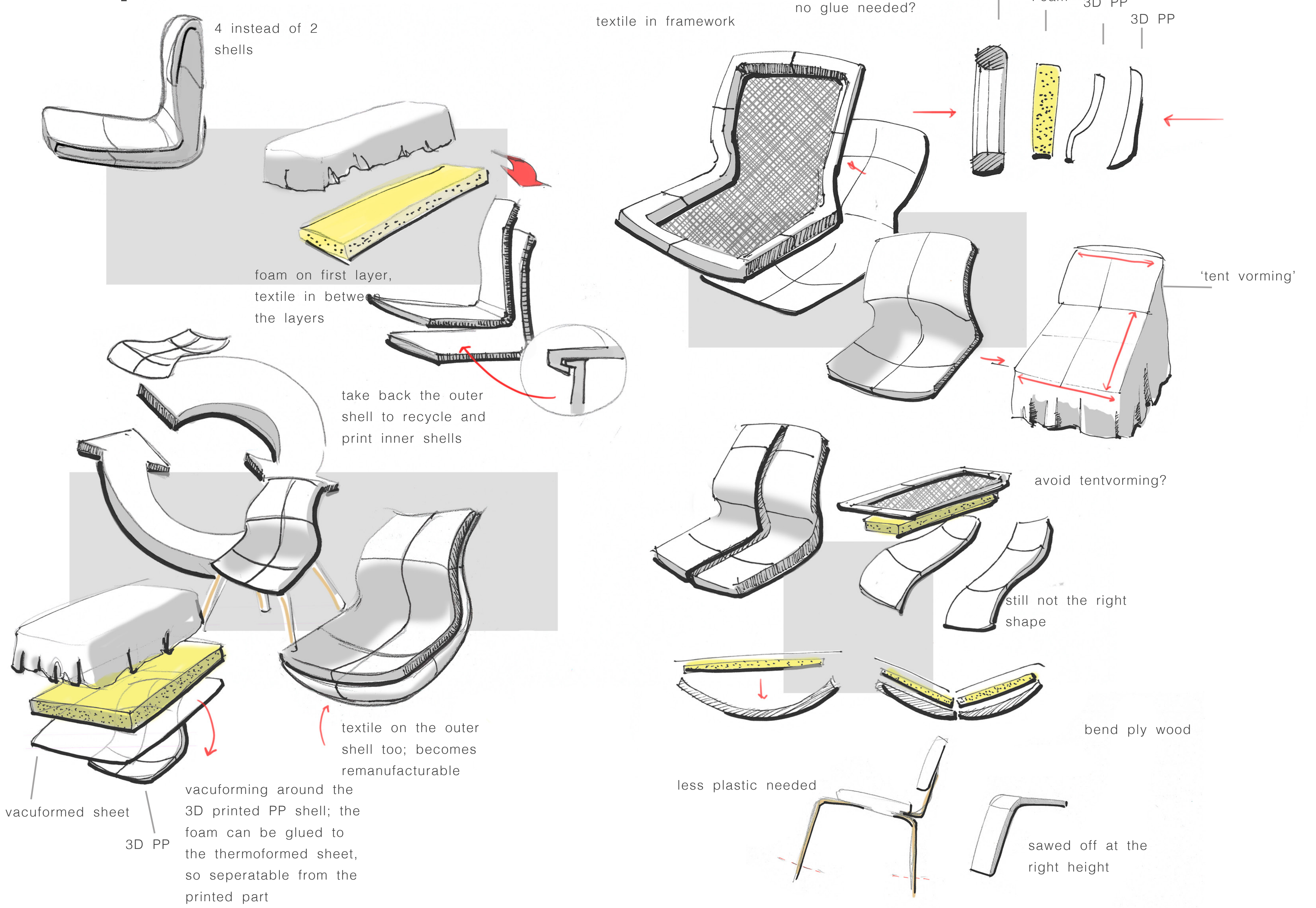
20 mm HR 45 | 30 mm HR 43 | 30 mm SG 40 | 35 mm SG 40 | 35 mm & 20mm | 30 mm SG40 & 20mm two pieces SG40

20mm HR 45 | 30mm HR 43 | 30mm SG 40 | 35mm SG 40

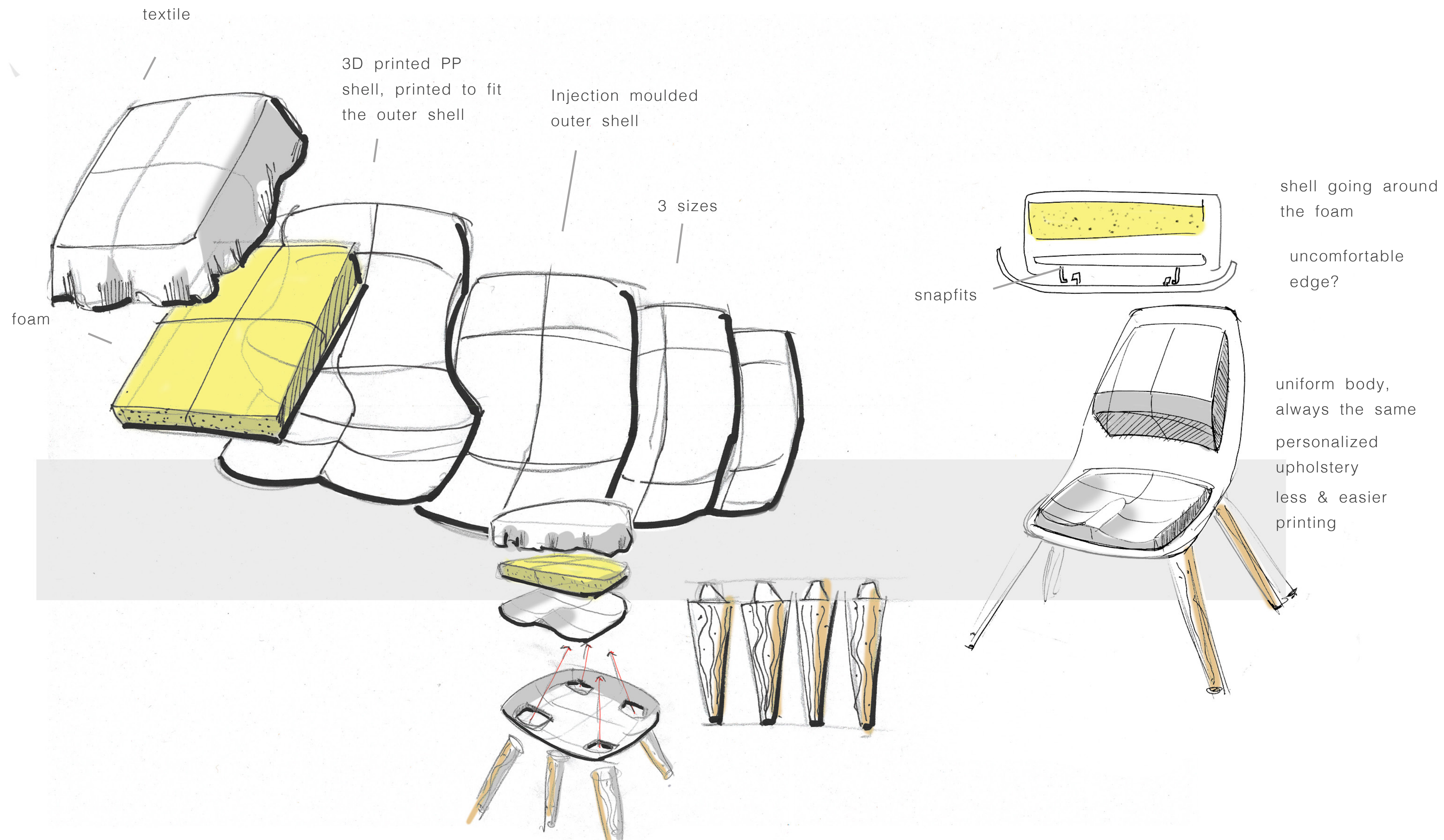
how to print?



how to upholster?

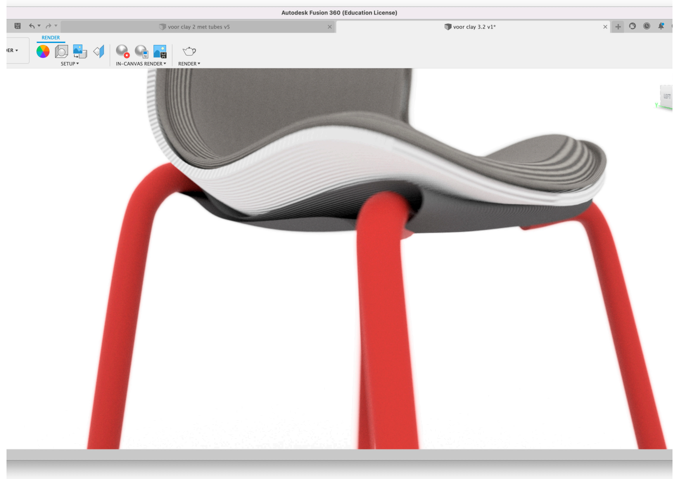


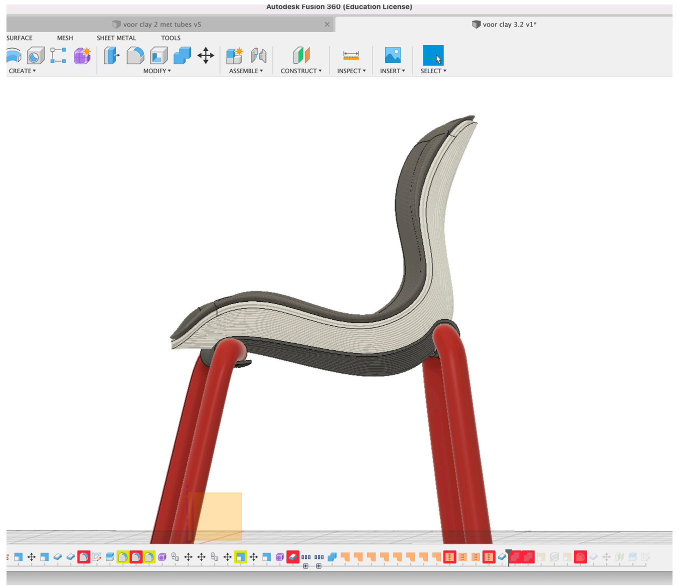
how to upholster?



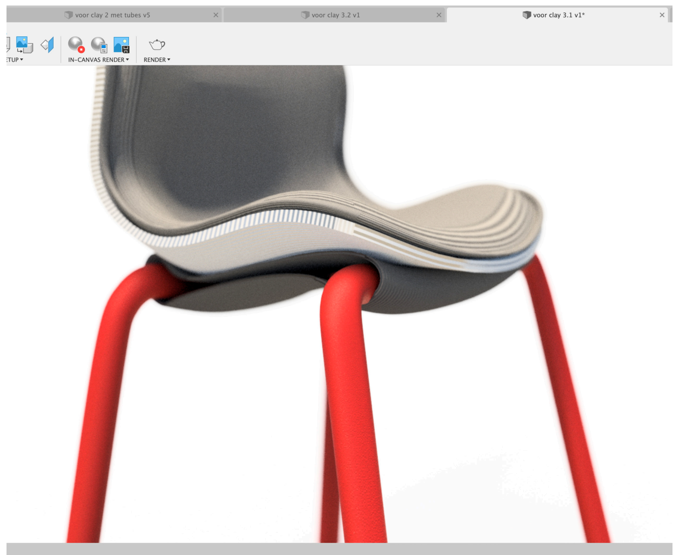
From these scale models, it turns out that printing perpendicular to the symmetric plane (third column) requires the least amount of support material and the least amount of finishing, with the best end result. At the same time, the material breaks at a different location. Splitting the leg area would be a better option as it can be reinforced by the legs. Other interesting outcomes from these test were the concentric circular printing pattern of the images in the first column. Also the last option, where the print lines are slanted compared to the exerted force, did not break, only bend.

appendix I: development progress

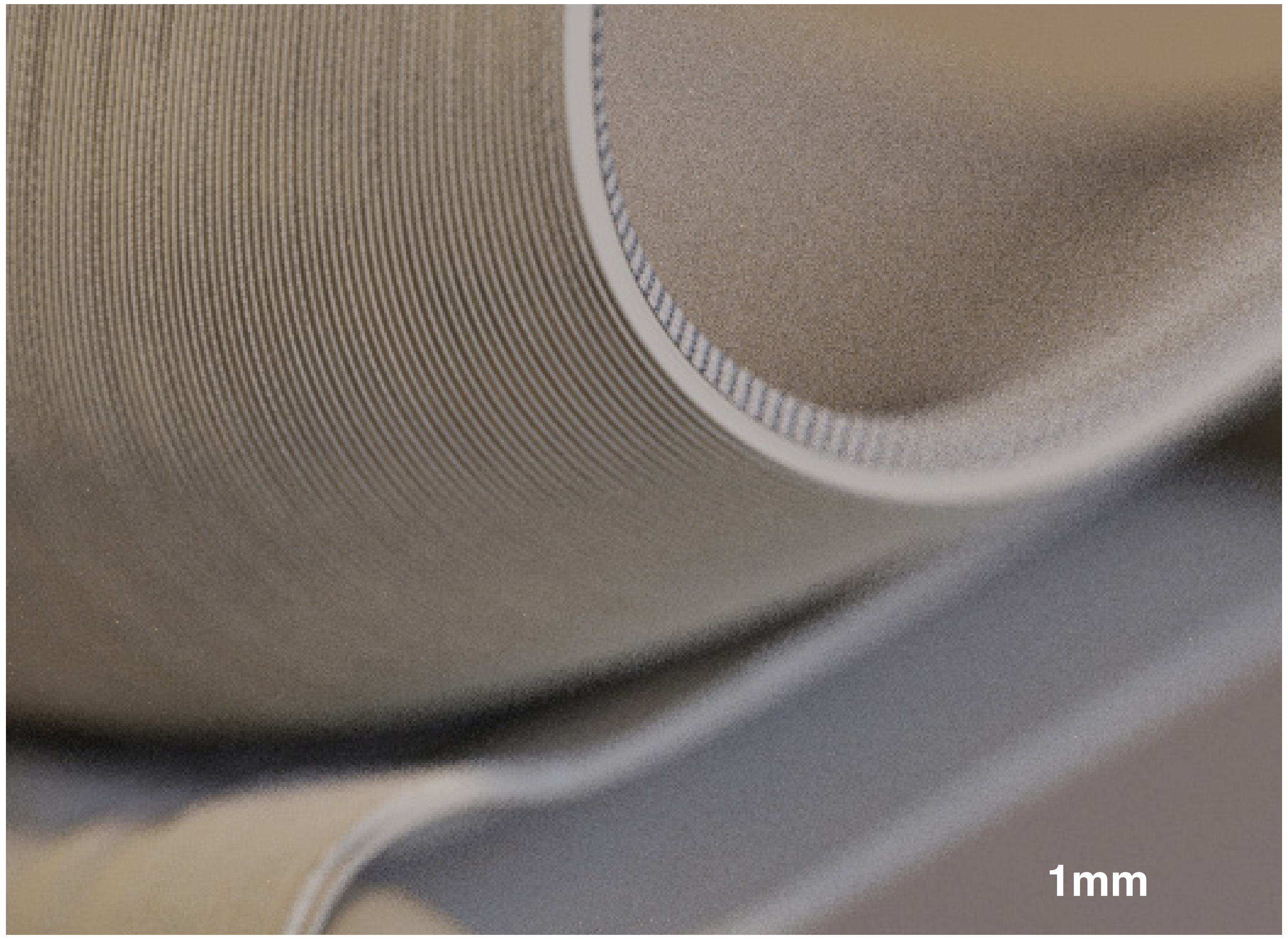



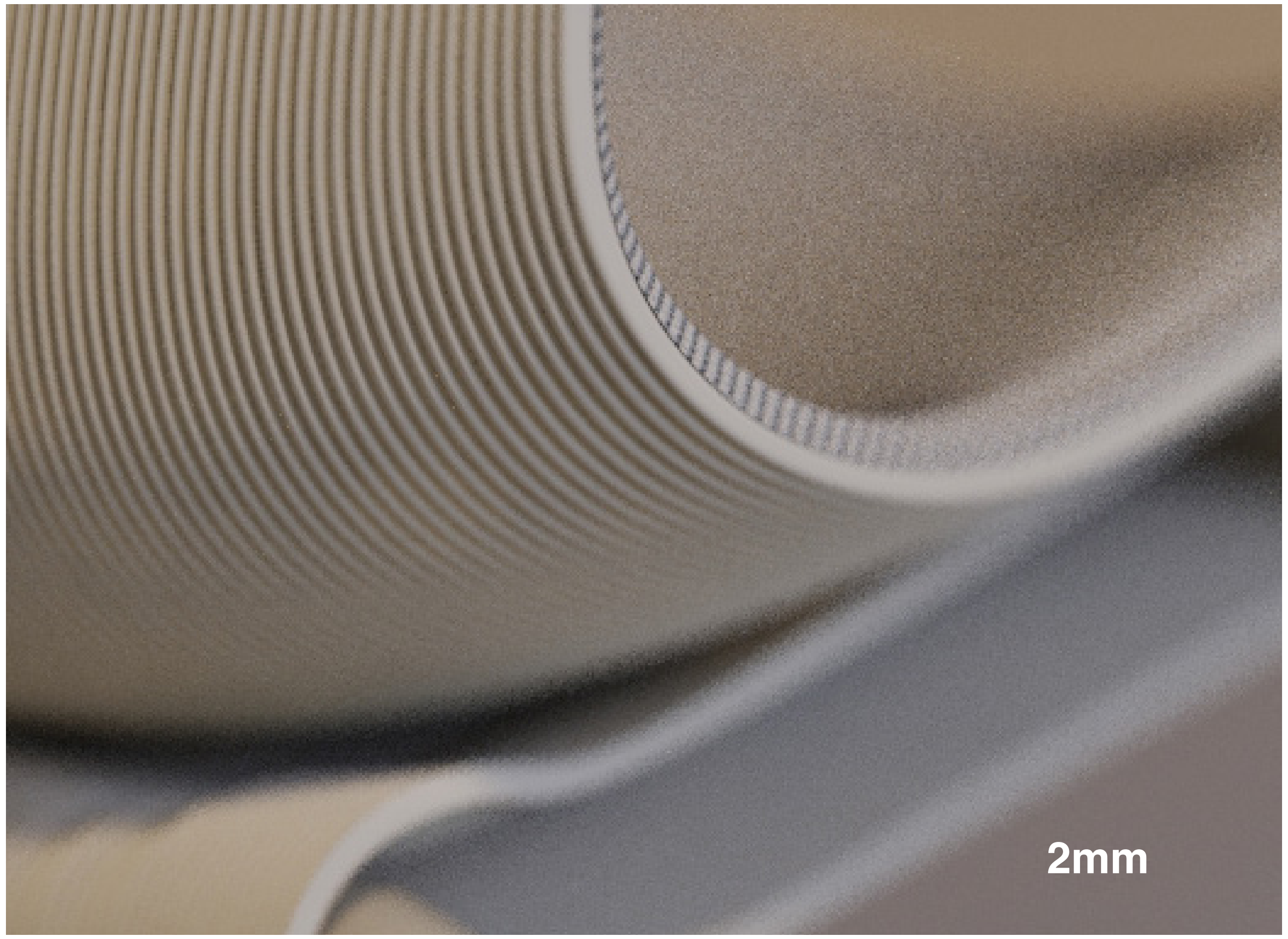





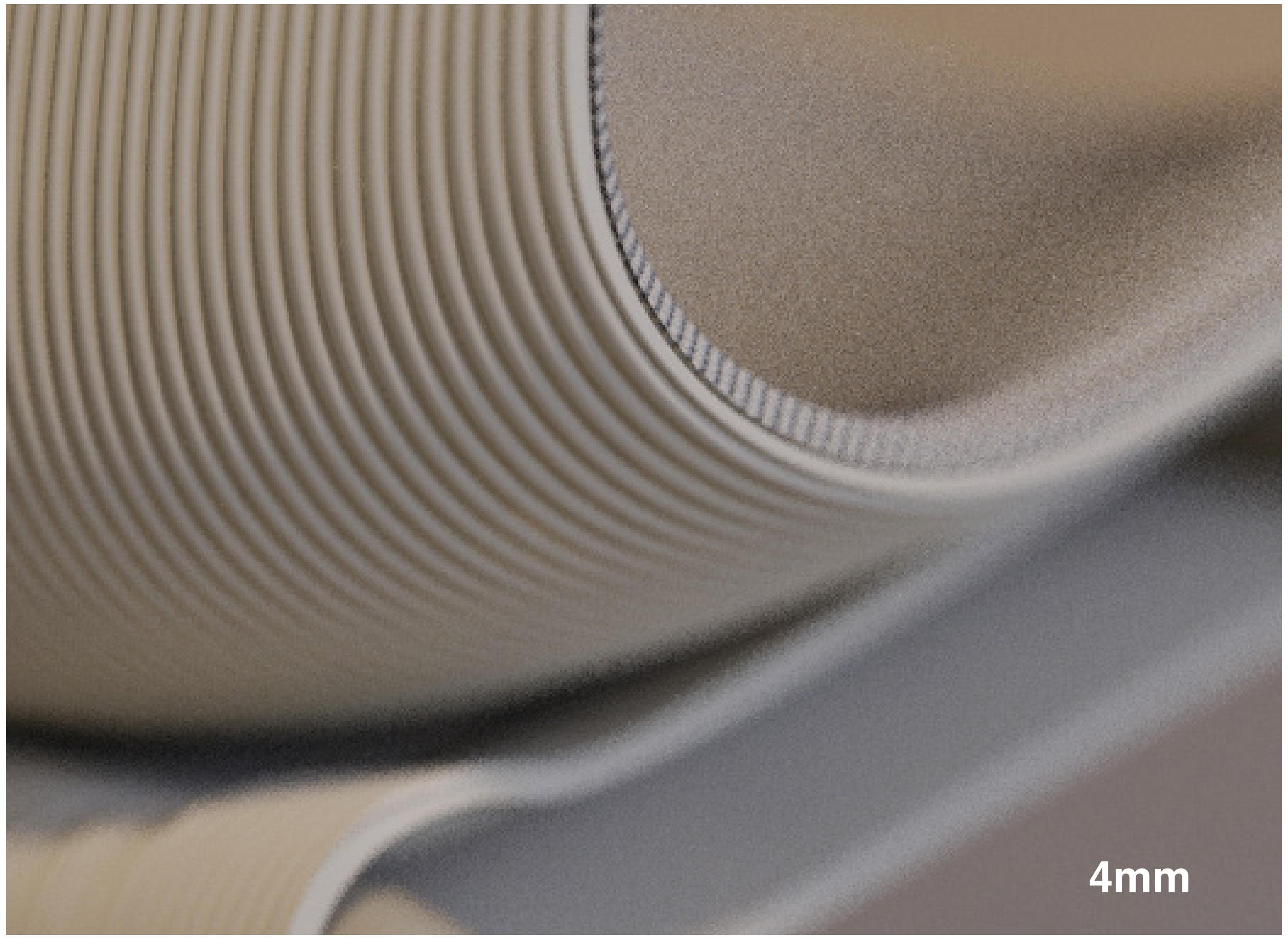


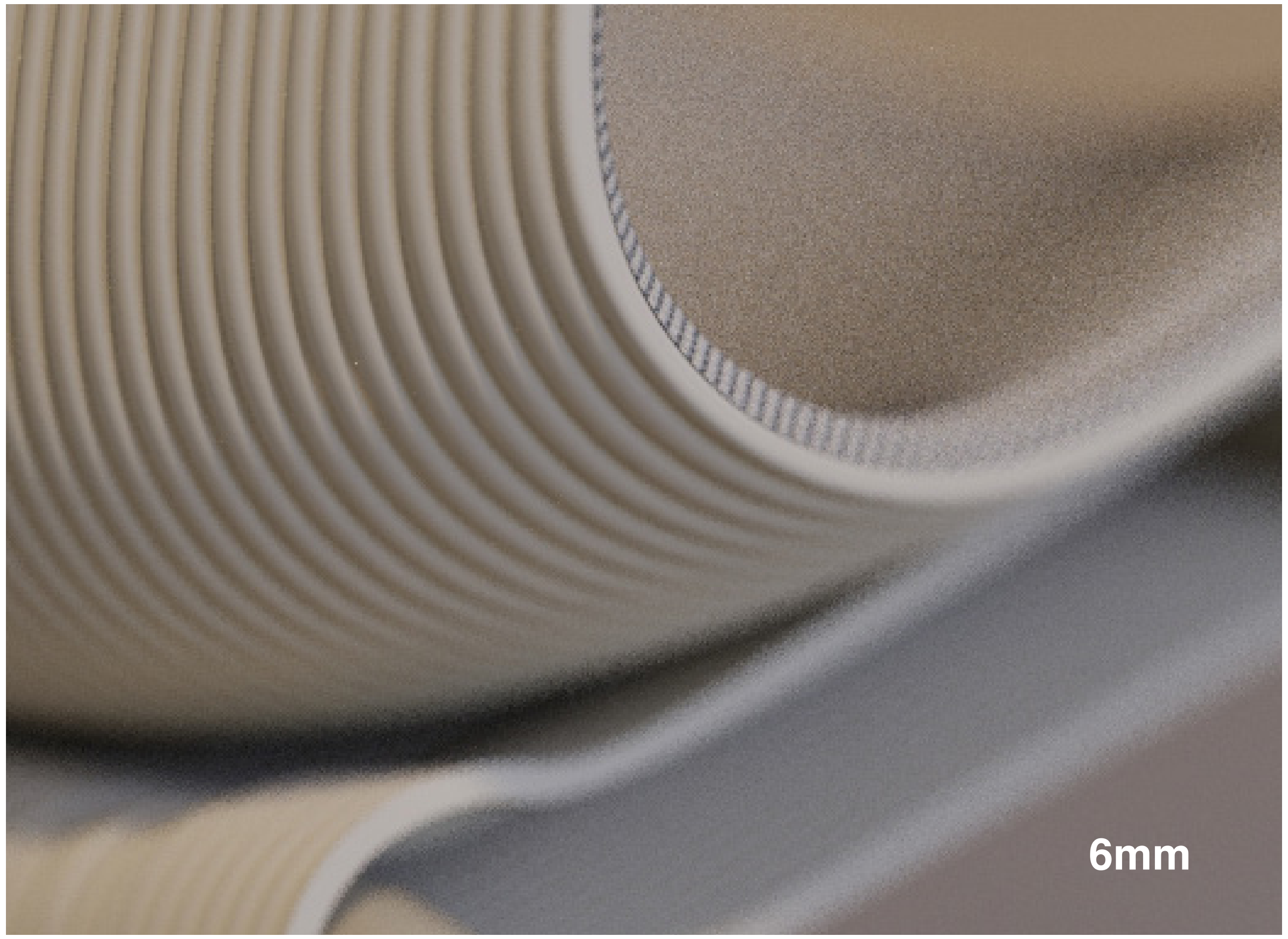

appendix I: development progress



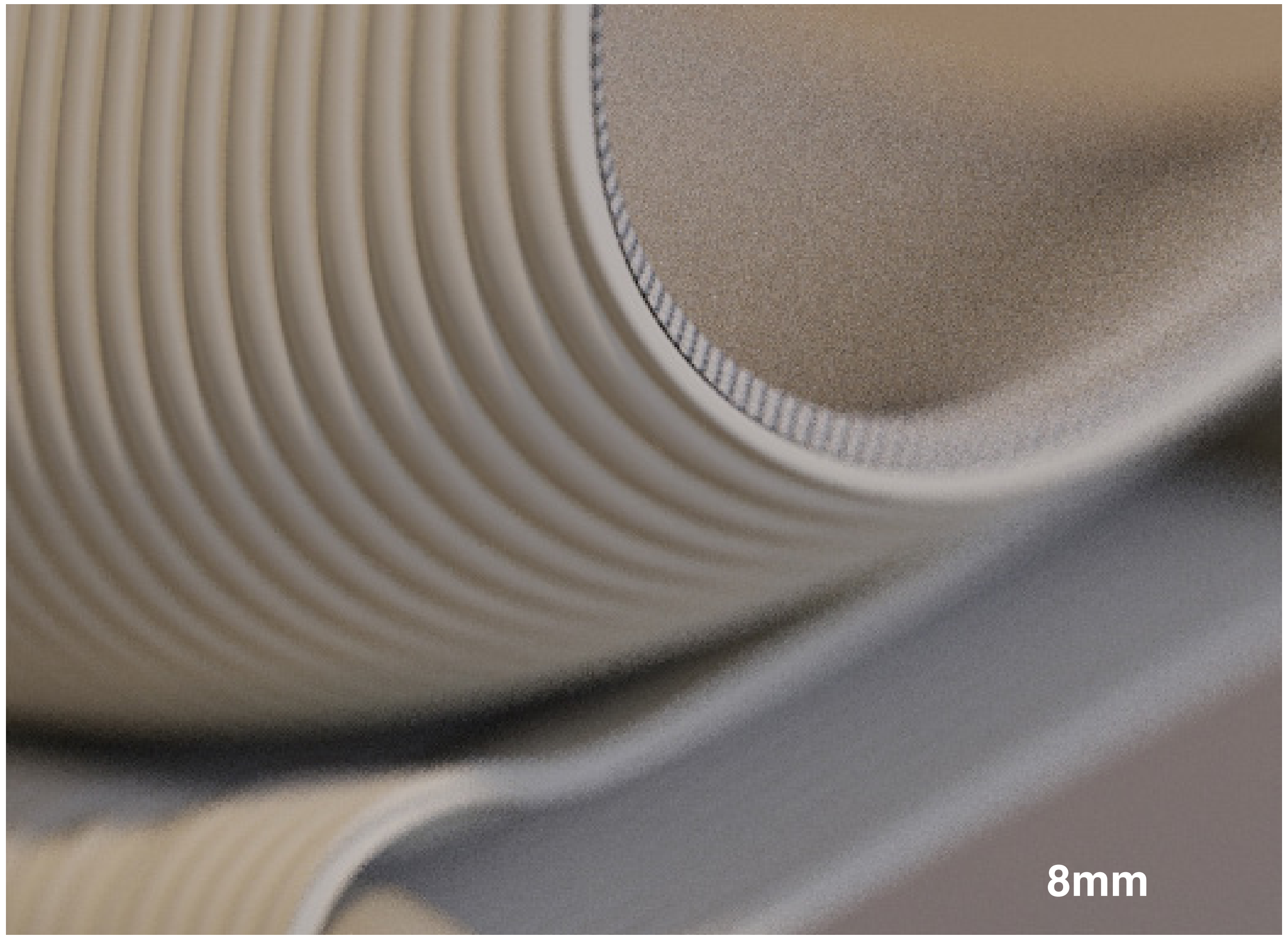


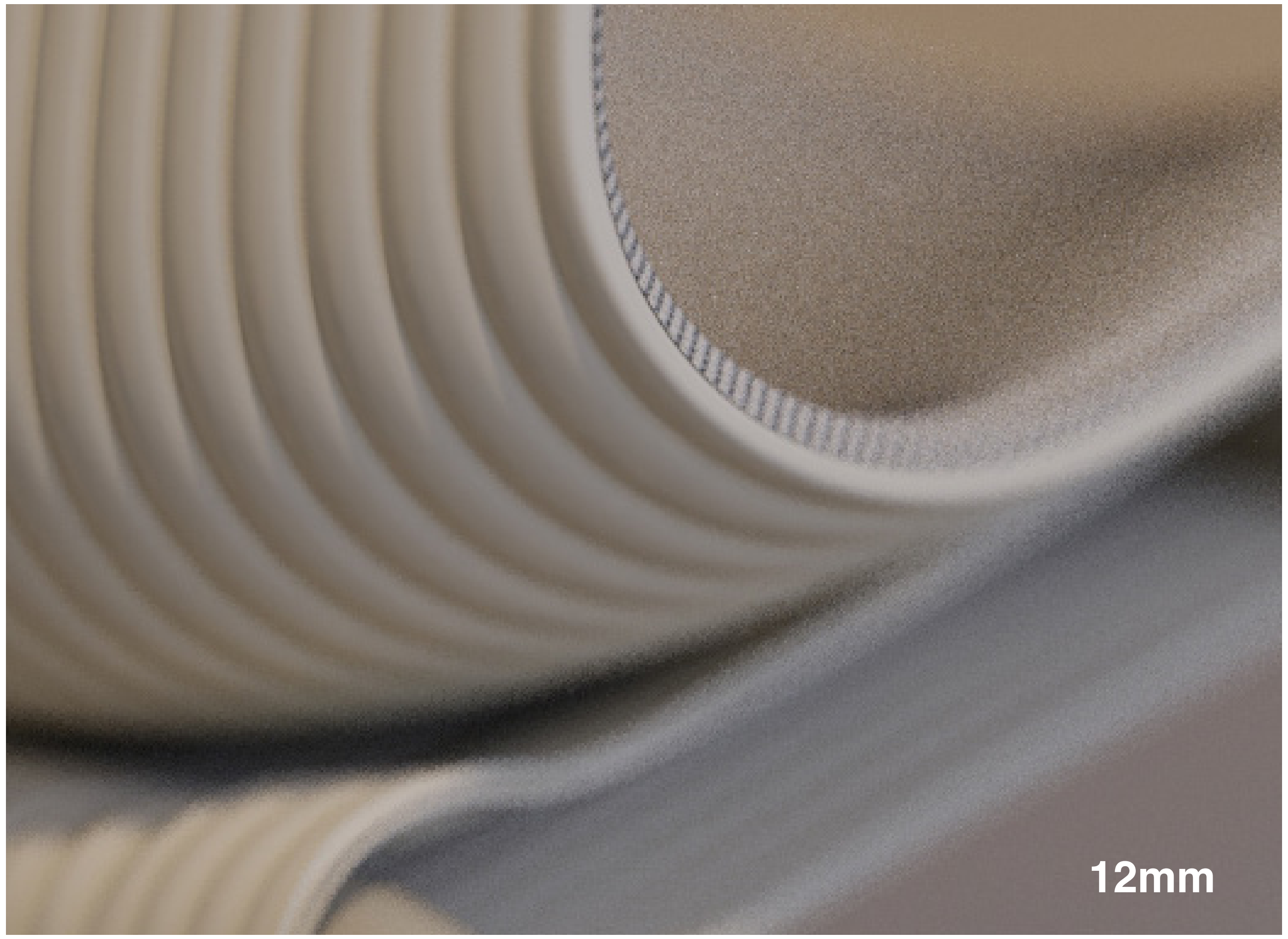
appendix J: layer height visualizations

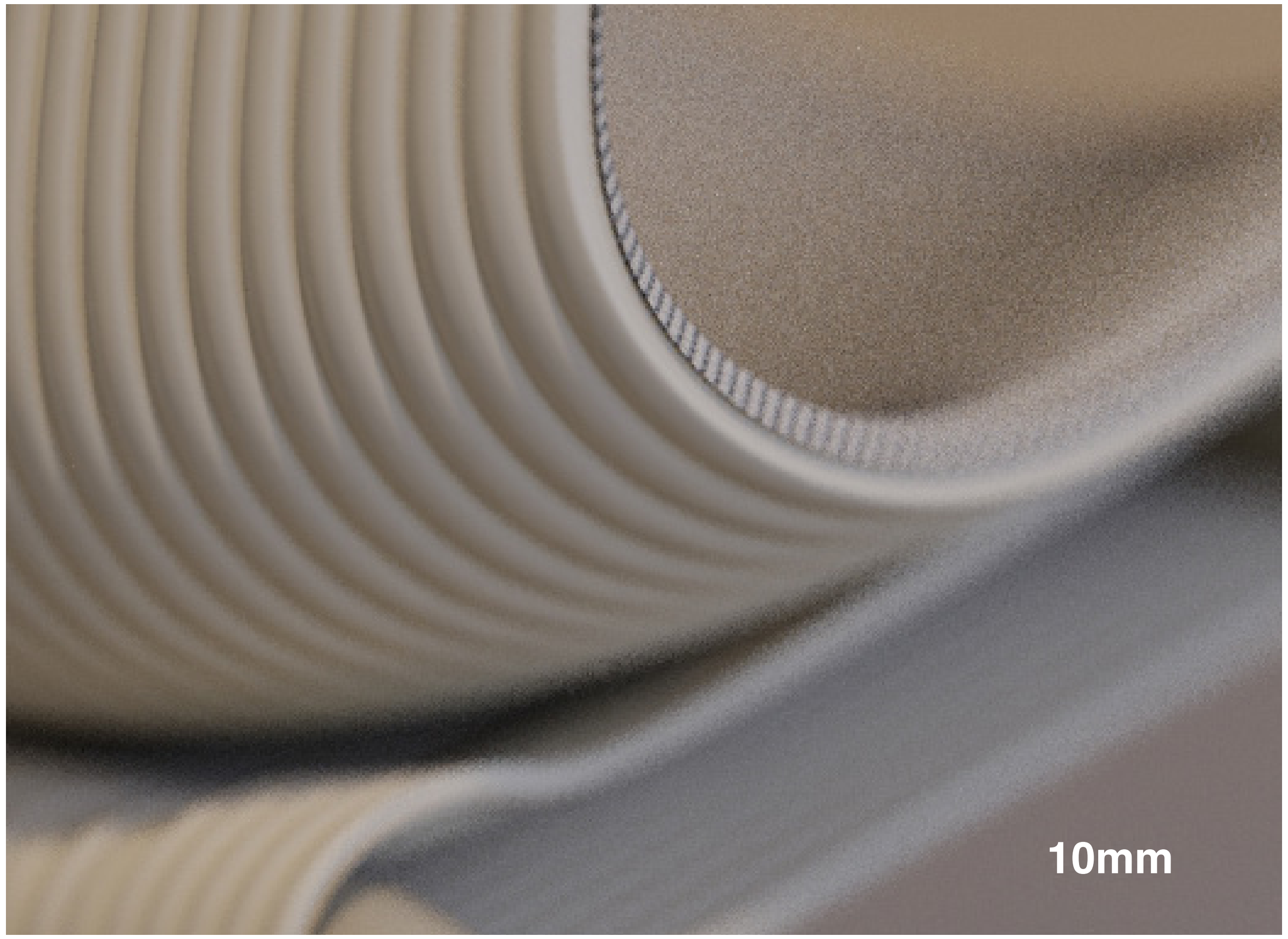


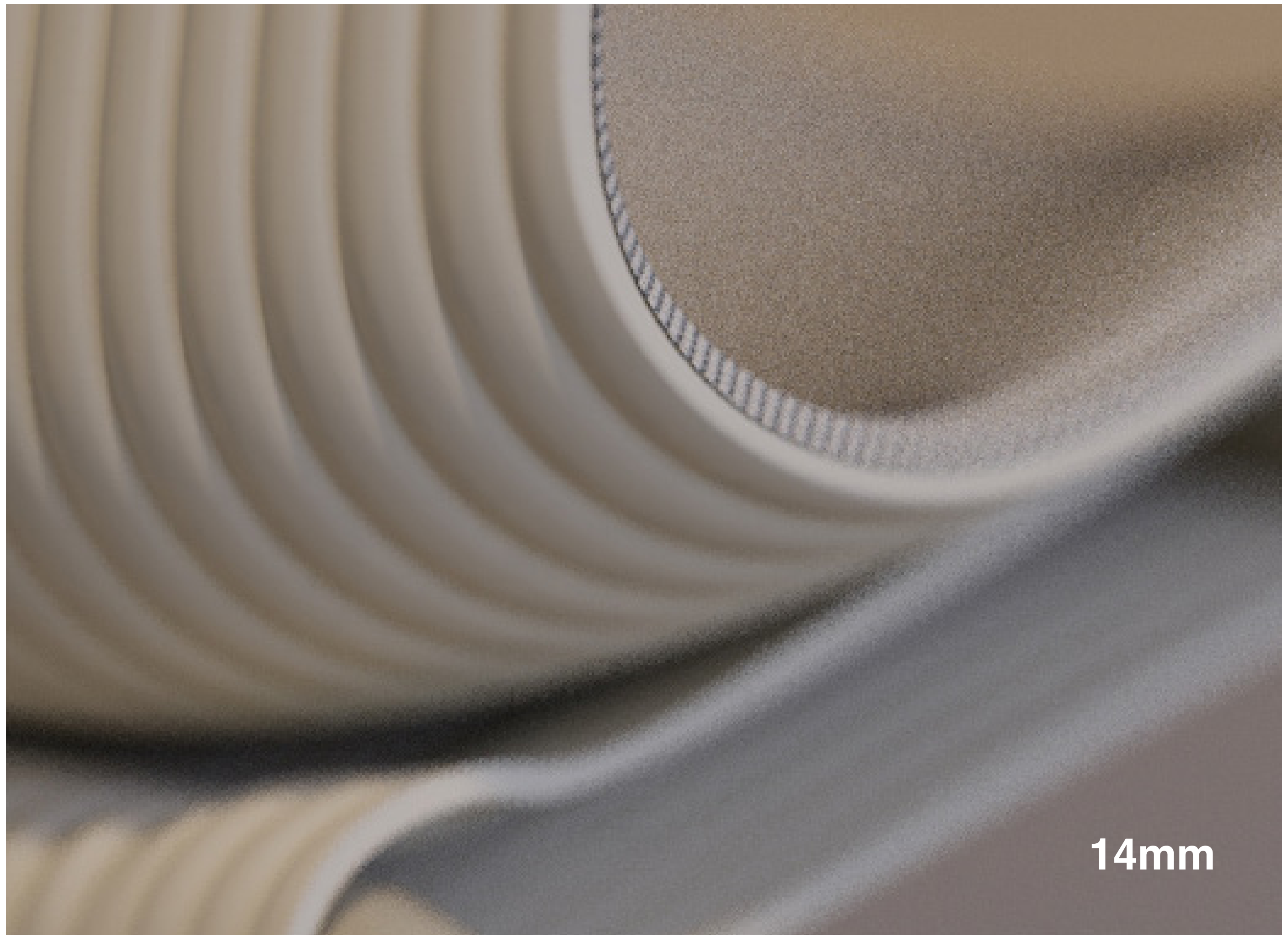


appendix J: layer height visualizations

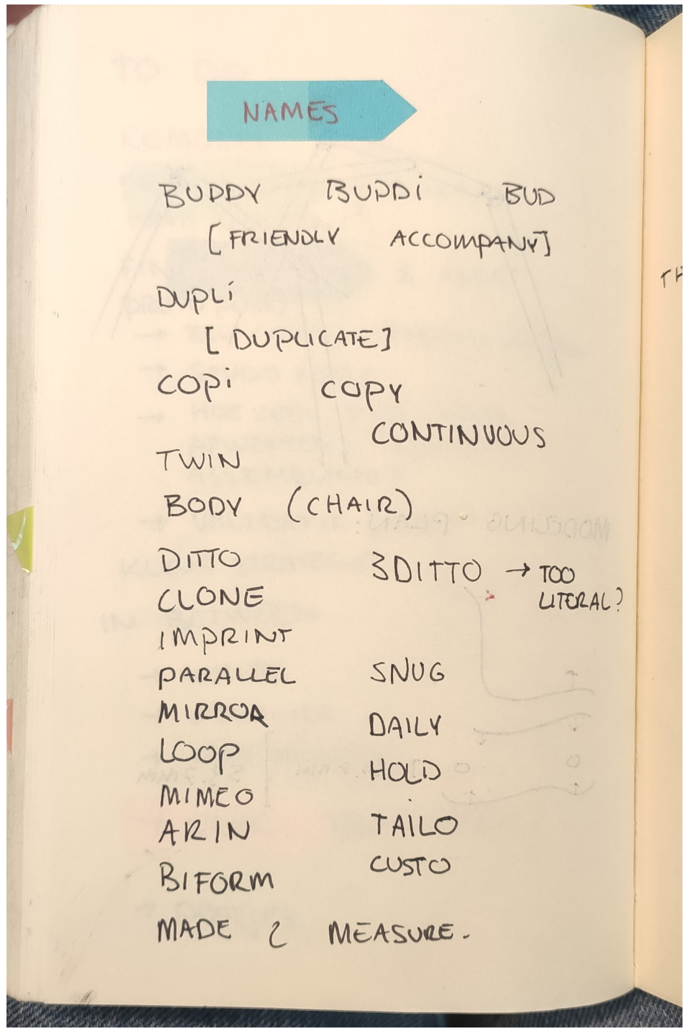




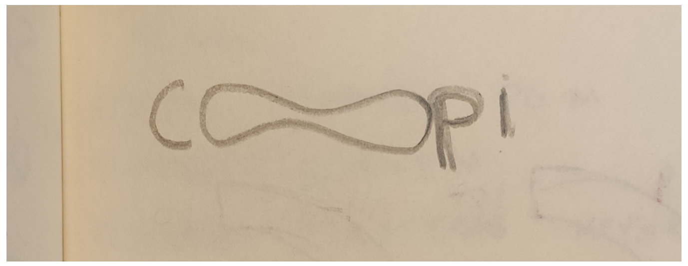




appendix K: naming and branding



brainstorming concept names



first logo sketch

appendix L: visual differences between CAD and prototype

isometric view

perspective view

The isometric view shows a wider posture of the Coopi. The perspective view shows an image that is closer to what can be seen in real life (and photographed with a 50-70mm lens). On small hand-held products, the perspective does not really influence the entire perception of a product. In the case of a relatively large product, the difference is more considerable. The client is advised to iterate on the design until the real life perception is closer to the intended posture of the isometric view.

difference intended and achieved leg bend radius

As mentioned. The design was aimed to utilize a tubular frame with a diameter of 33,7mm and a center line bend radius of 60 mm. However, due to time limitations, there was no time for the leg frame to be produced professionally. Instead, the frame was build by welding straight tubes with 'welding elbows' (a pre-bend piece of tubing). Unfortunately, these welding elbows were unavailable with a radius of 60 mm, instead, a radius of 45 mm was used. The result is seen in the image above, where the left chair has a radius of 60 mm and the right chair has a radius of 45 mm. The prototype resembles the chair on the right, while the chair on the left was envisioned.

Evaluation

Method: After letting the users work while sitting on the Coopi for 15-25 minutes, a qualitative interview was conducted. During the interview, the topics comfort, ergonomics, desirability, downsides, perceived worth were discussed along with any additional remarks.
All participants were also asked to look at the price spectrum of Appendix D and imagine where on the price scale, the Coopi would belong.
Subjects: 4 + designer evaluation

Coopi for Ricardo
Gender: M
Age: 26
Height: 174
Profession: photographer, business owner, designer

Sitting experience: It feels more supportive, very 'chill'. Normally I'd my lower back hurts. I rate my pain a 6 or 7, now it feels like a 4 or 5. I don't directly have negative comments. It's really nice that it 'folds around your back', it gives a cozy feeling.

I'd mostly see this at a modern start up. Everyone should have their own chair and own color. Moderne start up. But it could work for larger companies as well.

I wouldn't place this at my current house. It's too messy there. But would consider it more quickly if I would move somewhere else. If I'd own a stone floor, or cast floor, it could look really beautiful on that.

I'd style it red with with. If the house is somewhat neutral, bright colors would really help to let the chair jump out.

Ricardo gives the Coopi a price tag of slightly above €400
————————————————————-

Coopi for Anne
Gender: F
Age: 28
Height: 172
Profession: art director, interior stylist

It felt comfortable, but not really for my body. My hips are broader. My hips feel tilted forwards. It feels like I was sitting straight, but that my back was too curved forwards. I would love to spend too long in that position. Other than that, it felt nice.

I thought the seat was really warm, too warm.

I'd imagine this chair in most work situations. It is an
would love to spend too long in that position. Other than that, it felt nice.

I thought the seat was really warm, too warm.

I'd imagine this chair in most work situations. It is an ergonomic chair. I'd also like it at home, anywhere you would not want an ugly desk chair.

When looking for furniture, I'm looking for striking furniture. Also quality is important.

The concept is valuable, if you have a correct posture; that's worth something.
Unfortunately, you can't share the chair, that a downside, but it's not the worst.
I'd only use it to work on it, not for dining. We already have 'chill' chairs for that, I'd like to keep work and food separated. The chair then also feels more as a luxury just for working, instead of an everyday thing.

I think it would be important if the chair can easily glide on the floor without damaging it.
I like that it's a striking chair. I'd like to have 1 color for the chair, or a combination of bright colors. Yellow, green, red and blue are my favorites.

Sustainability is of value. I expect my body to stay the same. So I do see this as a sustainable purchase because I'd be sitting in it for years. Printing in recycled materials would be of added value, but it shouldn't cost more because of it.

It would also be of added value if it would be locally produced, for example with social workplaces (sociale werkplaats)

I'd also find it 'relaxed' if I could approach the company for service, for example in case of damages.
Changing colors after a while would not add value. I don't need another color every two years. It's a design item, so you get one, and that's it.
Also, you don't need to pick out of 50 colors. It's nice to have a pre selected color. That the vision of the designer, I'll make my house fit to it.

Anne give the concept a price tag of €600.
If it really checks every box, it would even be worth €1000,- but not in my current stage of life.
The most important is that price, styling and

quality are in balance. I think the fact that it is ergonomic is more important than design, but even more important is that it's in balance. There are also really good, but ugly chairs. Price, beauty and ergonomics need to be in balance.

I think it should be easy to dis- and reassemble for when you are moving. If it comes in a good box, I would keep that, just like the box of a laptop, for example.

————————————————————

Coopi for Mark
Gender: M
Age: 26
Height: 189
Profession: freelance graphic designer, business owner

I don't think it sits great. It's not my posture, clearly.
The curved bottom of the seat feels like it pushes my thighs together.
Also the back rest is too short for me.
The hollow shape feels comfortable. Also the softness of the foam is good, just comfortable. If it was my own shape, I could imagine it to be 'chill'. As cast.

The concept in itself is strong. For home working and ergonomics, it's a strong concept, I don't see disadvantages.

I'd prefer the chair to be one color, that more beautiful and more timeless. Which color I'd pick would depend upon the house. I like this yellow. I would not choose basic colors such as white or black. I do like the idea of having a personally signed label/tag on the side of the chair.

The biggest value is that it blends in your room instead of a big black chair. It can really become part of your interior, something that a big black desk chair couldn't. It is also a more friendly looking chair.
I'd be skeptical of measuring my body with an app. I wouldn't trust that.
I expect that the product would have beautiful and smart packaging. The packaging should be natural, and smart. The unboxing should feel like a luxury product.

Since it's a personal product, the contact with the company and the service should be very accessible. I'd like to visualize the chair digitally, like Nike-by-you

Mark give the chair a price tag of €620,-

I don't think it belongs in the highest range, it just doesn't have the name or reputation. If you would sell it to Vitra, you could ask much more for it. Or Ahrend (to a lesser extend). Or the marketing campaign and branding should be really strong. But of €620, a lot of people would still buy it.

Coopi for Chantal
Gender: F
Age:28
Height: 173
Profession: freelance digital marketeer

It feels very sturdy, that's nice. I have the feeling that it is not optimized for my body, especially in the back area. My thighs are also too wide. After a while I think it would become uncomfortable. The lumbar support is too low for me, but if I slide down a bit, it feels very 'chill'. It feel supportive and I think that's good for you.

I think it would also stay comfortable. It is not really a chair that has pressure points, there are no points that will start to irritate.
It is not a 'log' chair. It's beautify to put in a room and doesn't take too much space. I feels ergonomically responsible.

The shape of the seat is very visible. It already looks comfortable/ergonomic. You can see that it is shaped after someone.

If I think about the benefits of ergonomics, I would really want arm rests. Maybe you could add those?

I like the color, but it won't be for everyone. I'd like a darker color, that will also stain less. You should have a couple color options: a couple with bright colors and a couple of more neutral. You don't need a huge range of colors, I think

The concept fits best in the living room.
Is it really better than a standard living room chair? I'm not 100% sure. Perhaps the curvature in the lower back is an advantage, but since it doesn't have arm rests, does it really add that much value? I can imagine that it does attract a lot of people though. Since it is a concept in itself, it's something that people could value. People that are materialistic. Lawyers or marketing employees for example, they really like to have something to boast about, its not a simple Ikea chair, that adds value to people.

appendix M: user validation

It would not be worth over €1000,- it just doesn't compete to the benefits and quality of a high end office chair. Between €600,- and €700 would be a good price.

Coopi for Lean
Gender: M
Age: 26
Height: 180
Usually, it would be incorrect for a designer to take part in a user validation. But in this scenario, the chair is shaped after the designer, so the experience seems very relevant.

Sitting experience:
-I completely forgot that I sat in it after 30 seconds.
-The contact area between chair and thighs, on the edge of the seat, is a little harder. The seat could have sloped down just a little bit more there.
-The buttock and back area feel very comfortable.
-The back rest seems a little bit on the short side
-The lumbar support feels good, but feels like it had to be 1 centimeter higher.

Personal taste:
-Rather have monochrome
-I'd prefer it to be a bit larger
-Maybe different color stitching would look nice
-Worth: 600
-Preferably, the seat would be a bit more flexible.
-I'd place it in a little larger house than I have now. I see it as a design piece and unique concept, so I would not spend money on it if it doesn't 'shine'. In an ugly, temporary, small, messy living room, it does get the attention it deserves. I would only get it, if the living room 'serves' the design of the chair.
-I love the yellow, but it already seems to get dirty quite quickly.